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NOISE
AND
VIBRATION

IMPACT ASSESSMENT

HAMILTON-WENTWORTH RAPID TRANSIT PROJECT

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For Submission By:	Metro Canada Limited
To:	The Regional Municipality of Hamilton-Wentworth

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PREFACE

The purpose of this report is to analyze potential noise and vibration impacts along rapid transit Route 'W', selected as the preferred route for further study by Regional Council on July 21, 1981. This report was prepared by Wilson, Ihrig and Associates, experts in all types of transit noise and vibration, and subconsultants to Metro Canada Limited for the Hamilton-Wentworth Rapid Transit Project.

The analysis in this report is based on a concrete guideway configuration, although in some locations Regional Council may choose a composite steel and concrete guideway as its preferred configuration. An analysis of the differences between the concrete configuration discussed in this report and the alternative (damped or undamped) steel guideway configuration is provided in the "Steel Alternative Guideway Study - Phase 1 and 2 - Feasibility Report". A summary of this analysis has been extracted and is attached here in order to give the reader an appreciation of the noise and vibration characteristics of steel as compared to concrete guideways.

The conclusion that may be drawn from this comparative analysis is that the noise and vibration characteristics of the concrete configuration are virtually identical to a damped steel guideway alternative. Therefore, conclusions presented in this noise and vibration study will apply equally well to either guideway configuration.

NOISE AND VIBRATION SUMMARY PREPARED BY
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FROM THE "STEEL ALTERNATIVES GUIDEWAY STUDY
PHASES 1 AND 2 FEASIBILITY REPORT"
METRO CANADA LIMITED, HAMILTON, ONTARIO,
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4.4 Noise and Vibration Summary - (See Appendix 8.4)

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Compared with other transit vehicles in use today, the ICTS vehicles proposed for Hamilton are considerably lighter (21,000 kg @ crush capacity) and operate at much slower speeds (72 km/hr cruise speed). Consequently the wayside noise from the ICTS system is, in general, significantly less than that associated with other transit systems.

The Region of Hamilton-Wentworth has expressed a desire to investigate the feasibility of steel in construction of the elevated guideway as an alternative to an all-concrete structure. However, based on existing experience in the transit industry, the use of undamped steel plates as part of the composite steel/concrete elevated structures can result in community noise levels due to train pass-bys that are potentially unacceptable. An analysis was made to determine the comparative wayside noise levels of trains operating on three alternative elevated guideway designs and the relative impact on the wayside community. The three designs are damped and undamped steel, and concrete.

Based on measured noise and vibration data taken by Metro Canada at the ICTS Transit Development Centre in Kingston, Ontario, and a prediction model derived from a combination of empirical data and theoretical analysis, noise levels due to train pass-bys have been projected for the composite steel/concrete guideway with and without damping. These were compared with the measured data obtained at the Transit Development Centre which has an all-concrete elevated guideway.

The proposed Hamilton ICTS will be routed through three basically different areas of the city: Central Business District (CBD), Escarpment, and Mountain. Each of these areas has a unique existing noise environment and requirement that should be taken into consideration. An assessment of the impact of wayside noise on the community in the three areas was made using the predicted wayside noise determined by this analysis for the three alternative elevated guideways. To determine comparisons of the predicted wayside noise the resulting interior noise in typically constructed buildings was determined for typical train pass-bys.

The general conclusions that can be drawn from this study are:

(1) Even with the expected higher levels of structural noise radiation, the noise actually radiated from the wheel/rail interaction and the transit cars is expected to dominate the A-weighted wayside noise levels from normal operations on both the concrete and steel/concrete composite ICTS structures, at least for outdoor noise.

(2) With the use of constrained layer damping treatment applied to the steel plates, the ICTS steel/concrete composite structure is expected to provide essentially the same performance regarding wayside noise as the all-concrete structure.

(3) The outdoor A-weighted noise levels are not expected to differ significantly with either the concrete, undamped composite, or damped composite elevated guideway.

(4) In the CBD, unless there is now or should be in the future an area with significant number of lightweight residential structures (as contrasted to high-rise masonry structures), there will not be any significant difference in noise impact from the three types of elevated guideway.

(5) In the Escarpment area the noise impact will also be essentially the same with any of the three types of guideway, because this area is primarily open space. However, if there are any lightweight residential type buildings located near the guideway in this area, the undamped steel/concrete composite guideway would result in greater interior noise levels at low frequencies, and for such conditions damping should be used.

(6) In the Mountain Region, either the all-concrete or damped (using constrained layer damping) steel/concrete composite guideway would result in the same noise impact. However, the high levels of low frequency rumble noise from the undamped steel structure will result in a significantly

increased impact inside buildings compared with the other two alternative guideways. Only in areas where there is a very high volume of night time commercial traffic present would it be possible to use the undamped composite structure. The evaluation of those areas for which the steel requires damping should include consideration both of the first and second row of houses near the guideway structure.

(7) A cost estimate using presently available data for the purchase and installation of constrained layer damping (not including the steel damping plate) was made. The estimated cost is $170/m per single lane guideway beam. This assumes a 37% area coverage of the steel plates in the guideway, a typical figure for such damping applications.

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INTRODUCTION AND SUMMARY

The proposed Hamilton ICTS will be routed through three community areas: Mountain, Escarpment, and Central Business District (CBD). Each of these areas has a unique existing noise and vibration environment, and each area has particular requirements for minimizing the potential adverse noise and vibration impacts inherent with a new transportation system. An assessment of the impact of wayside noise and vibration has been made in each of these areas and at buildings with uses which are particularly sensitive to noise and vibration.

The rapid transit system planned for the Hamilton-Wentworth area is based on the Intermediate Capacity Transit System (ICTS) design developed by Metro Canada Ltd. The vehicle employed in this system is driven by a linear induction motor along standard gauge track. Compared with other rail transit systems in use today, the ICTS vehicles are considerably lighter (21,000 Kg compared with 50,000 Kg @ crush capacity) and operate at much slower speeds (72 km/hr maximum). Thus the wayside noise and vibration produced by the ICTS will be much lower than that associated with other systems.

The proposed initial ICTS route will consist primarily of concrete aerial structure with a single length of tunnel connecting the Central Business District and Mountain areas.

The potential noise and vibration impacts have been determined utilizing the following:

1. The ambient noise survey performed in March and April 1981 by Marshall, Macklin, Monaghan/Hatch Associates.
2. A limited scope ambient vibration and noise survey performed in August 1981 by Wilson, Ihrig & Associates (WIA).
3. Noise and vibration data taken by Metro Canada Ltd. and the Toronto Transit Commission (TTC) at the ICTS prototype test track in Kingston, Ontario.
4. Prediction models for wayside noise and vibration based upon the data obtained in item 3 (above) and from measured data obtained at other light and heavy rail rapid transit systems.

Much of this impact assessment is based upon the currently available data provided by Metro Canada from tests performed using the dual guideway concrete aerial structure and the at-grade slab track at the test facility in Kingston; Ontario. If the guideway and vehicle system characteristics ultimately used for the Hamilton ICTS are significantly different from those used in this analysis, the noise and vibration levels associated with the operation of the ICTS can be exected to be somewhat different than those predicted in this report.

The general conclusions that can be drawn from this impact assessment are:

1. Although the noise from the ICTS system will not be unnoticeable, there will be no adverse noise impact when compared with the City of Hamilton Noise Bylaws, MOE (Ontario Ministry of the Environment) Guidelines, and transit industry environmental standards.

2. The vibration produced by trains traveling on the aerial structure will have no adverse impact anywhere along the system as long as the aerial structure column footings are at least 5 meters from any building foundations. Further analysis is recommended during final design at those locations where column footings will be between 0 and 10 meters from a building foundation.

3. The vibration produced by trains traveling underground will create no adverse impact when compared with criteria developed from other transit systems and environmental standards. However, during final design, further detailed analysis is recommended in the shallow tunnel area along Upper James Street between Brucedale Avenue and Fennell Avenue in order to ascertain that there will be no adverse vibration impact once the final alignment and depth of the structure are determined.

4. Although all applicable noise criteria are achieved without the use of any special noise reduction measures, during final design, further analysis is recommended of the noise levels produced by the ICTS trains at the second and third story apartment units of the building located at Hughson and Young Streets since some

of these apartments have balconies which will directly face the alignment. Further analysis is also recommended of the noise and vibration levels produced by the ICTS trains where the structure crosses over a corner of the Canadian Football Hall of Fame building.

5. In several areas which now have extensive bus traffic, based on proposed bus rerouting, there is the potential for significant community noise reduction. For example, in the Gore Park, John Street, James Street, and Jolley Cut areas, the peak hour equivalent noise level (L_{EQ}) should be reduced by at least 3 dBA.

6. This impact assessment indicates that no mitigative measures are necessary to meet City Noise Bylaws, MOE Guidelines, or Industry Standards. Possible mitigative measures are discussed in the event that it is determined during final design that they should be implemented to reduce the noise and vibration impacts at those locations identified in conclusions 2, 3 and 4 (above).

AMBIENT NOISE AND VIBRATION BACKGROUND INFORMATION

Establishing the existing noise level or noise environment in a community requires measuring the noise at a large number of locations at several different times of day and, preferably, on several different days and times of the year. Community noise is a continually fluctuating entity dependent on many factors. Because the noise level does fluctuate over a relatively wide range, it is necessary to make measurements which are statistically significant and which can be analyzed on a statistical basis.

Establishing the existing vibration environment requires the same procedures and has the same general statistical variations as does the existing noise environment. Although reference is made throughout this section to ambient or community noise, this discussion for the most part is equally applicable to vibration.

The alignment will be routed through three community areas: Mountain, Escarpment and Central Business District. The proposed initial ICTS alignment will consist primarily of concrete aerial structure with a single stretch of tunnel connecting the Central Business District and Mountain areas.

In the Mountain area, the ICTS alignment will consist of a section of tunnel under Upper James Street, with a transition section leading to concrete aerial structure in the vicinity of Fennell Avenue. Between the transition area and Mohawk Road, the structure will consist of double guideway concrete aerial structure in the median of Upper James Street. There will be two stations in the Mountain area, an underground station at Upper James Street and Fennell Avenue and an aerial station at the southern end of the route at Upper James Street and Mohawk Road.

The Mountain area is primarily a residential area consisting of single family residences and some apartments. There are also several commercial areas along Upper James Street consisting of retail stores with some office space.

In the Escarpment area, the ICTS alignment consists of a transition section from concrete double guideway aerial structure through a portal to underground tunnel. The Escarpment consists primarily of wooded parklike space with only a few single-family residences.

In the Central Business District, the ICTS alignment consists entirely of concrete aerial structure except at the proposed yard location near Beckley Street. From Beckley Street south to the transition area the alignment consists of double guideway concrete aerial structure with an aerial station in the vicinity of St. Joseph´s Hospital. North of Beckley Street the alignment makes a loop around the downtown area with a single guideway concrete aerial structure. There will be two or possibly three stations. One station will be located on MacNab Street between King and Main Streets. Another station will be located on King William Street between John and Catharine Streets. A possible station location is on Catharine Street between King and Main Streets.

As expected, the Central Business District is primarily a commercial area consisting of office buildings and retail stores. There are some apartment buildings in the vicinity between Young and Forest Streets and between St. Joseph´s Drive and Freeman Place.

For commercial areas, with principally daytime occupancy, the possibility of intrusion from transit train operations is primarily a daytime consideration. In residential areas, the community ambient or background noise level is generally the lowest during the evening and nighttime hours, and the possibility of intrusion from transit train operations is greatest during this time period. Thus, in the commercial areas, the transit system design criteria are based primarily on daytime operations and noise levels. In the residential areas the transit system design criteria are based primarily on evening and nighttime operations and noise levels.

Although community noise data for the daytime in commercial areas and noise data for the evening and nighttime in residential areas are sufficient to establish the design criteria and evaluate the potential impact of the transit system, such measurements are not sufficient for a complete assessment of the community area or for determination of compliance with the City of Hamilton Noise Control Bylaw (Bylaw No. 79-292 passed in October 1979). Therefore, noise measurements should be made to give data on the existing noise levels for several different times of day. Complete 24-hour surveys of the noise level can be performed in order to obtain a complete statistical representation of the daily noise exposure in a community area. A number of 24-hour noise surveys as well as short term daytime and nighttime noise surveys were performed by Marshall, Macklin, Monaghan/Hatch Associates in March and April 1981 and presented in their report, "Hamilton-Wentworth Rapid Transit Study, Ambient Noise Survey, Environmental Assessment Task E-5". In addition short term daytime vibration and noise surveys were made by WIA at 10 representative locations along the proposed alignment on Thursday, August 27, 1981.

These additional short term measurements were made to obtain representative ambient vibration levels and to obtain additional noise data along the final proposed alignment. The Marshall, Macklin, Monaghan/Hatch Associates study includes only noise measurements and these were made over a relatively wide area in order to characterize the noise environment in all of the areas where various alignments were under consideration at the time of the ambient noise study.

From the Marshall, Macklin, Monaghan/Hatch Associates Ambient Noise Study, measurement locations 9, 10, 11 and 12 are in the vicinity of the final proposed alignment. Data obtained from these locations along with the 10 short term noise and vibration measurements made by WIA form the basis for evaluating the community noise and vibration along the route of the proposed ICTS System. The locations of the 10 noise and vibration measurement sites used by WIA are indicated on Figures 1 through 9 which show the proposed ICTS alignment. At each location, the sound level meter microphone and accelerometer were located in line with the set back line of the nearby buildings. A brief description of each measurement location is given in Table I. Results of the noise and vibration survey are presented in the respective sections, Existing Noise Levels and Existing Vibration Levels.

The results of the noise measurements and the description of the noise environments prevailing at each of the measurement locations in the community are based on a statistical analysis of the observed noise levels in decibels. The factors derived from the analysis are the levels exceeded 99% of the time, 90% of the time, 50% of the time, 10% of the time, and 1% of the time designated L_{99}, L_{90}, L_{50}, L_{10}, L_1, respectively.

L_{99} and L_{90} are descriptors of the typical minimum or "residual" background noise level observed during a measurement period, normally made up of the summation of a large number of sound sources distant from the measurement position and not usually recognizable as individual sound sources. The most prevalent source of this residual noise is distant street and highway traffic, but L_{99} and L_{90} are not strongly influenced by occasional local motor vehicle passbys. However, they can be influenced by stationary sources such as air conditioning equipment.

L_{50} represents a long-term statistical average or median sound level over the measurement period and does reveal the long-term influence of local traffic. If the instantaneous sound level is sampled over a measurement period, the sound level will be above L_{50} 50% of the time and below L_{50} 50% of the time.

L_{10} describes the average peak or maximum sound level occurring, for example, during nearby passbys of trucks, buses, automobiles, trains, or airplanes. Thus, while L_{10} does not describe the long-term noise prevailing it does describe the typical maximum noise levels observed at a point and is strongly influenced by the momentary maximum sound level occurring during vehicle passbys.

L_1, the sound level exceeded 1% of the time, is representative of the occasional maximum or peak sound level which occurs in an area.

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Because of some inherent deficiencies of the simple percentile measures described above in evaluating the noise exposure effects of short duration, high level sound (such as truck or bus passbys, the Energy Equivalent Level, L_{EQ}, has been developed and is widely used as a valid single-number descriptor of environmental noise. Because it is an energy integral over time, L_{EQ} represents the constant or steady sound level which would give the same energy level as the fluctuating value integrated over the total time period. Thus L_{EQ} places more emphasis on high noise level periods than does L_{50} or a straight arithmetic average of noise level over time. Some consider L_{EQ} a more useful measure than L_{50} for the average or typical noise exposure in an area and most recent evaluation systems such as CNEL (Community Noise Equivalent Level) or L_{DN} (Day/Night Average Level) use the energy equivalent concept.

EXISTING NOISE LEVELS

Table II presents a tabulation of the statistical analysis of the noise observed at each measurement site. All of the noise levels presented are in terms of A-weighted sound level in decibels, abbreviated dBA. This measurement scale is used because it has become accepted as the best compromise scale, using frequency weighting which approximates the hearing characteristics of the human ear. The A-weighted sound level shows good correlation of the subjective response of people and communities with measured noise levels. Also, most noise ordinances, standards and specifications are written in terms of A-weighted sound level.

Each measurement to determine the noise data in Table II consisted of a ten minute long continuous sample of noise at the site, recorded by means of a calibrated multi-channel precision magnetic tape recorder equipped with a laboratory quality microphone. The recordings obtained were later analyzed to obtain the statistical distribution and other descriptors of the noise levels. The tape recordings can be used in the future to obtain spectral analysis of the noise at the sites (such as octave band analyses) and are permanently retained as a record of the noise environment existing at the time of the measurements.

Review of the sound level data indicates that the L_{EQ} values are similar to the daytime L_{EQ} values reported in the MMM/Hatch Report at similar locations, (Locations 9, 10, 11 and 12). Thus it can be assumed that the nighttime noise levels reported at these locations in the MMM/Hatch Report give a relatively acurate characterization of the nighttime noise environment along the proposed ICTS alignment.

The lowest noise levels were observed at Location 6 in the Escarpment area near the location of the proposed north tunnel portal. The noise level is typical of a park or park-like environment with no nearby highways or boulevards. The major noise sources were motor vehicles travelling on James Mountain Road.

Locations 1 through 5 are located in the CBD. The highest noise levels were observed at Locations 1 and 2 both of which had a considerable amount of nearby vehicular traffic, with buses being especially prominant at Location 1. The noise levels observed at Locations 3 through 5 were somewhat lower due to less nearby vehicular traffic, the bulk of which is a block or two removed from these measurement locations. The noise levels are all characteristic of those in a typical CBD with commercial activity and buses on the major streets.

In the Mountain area, (Locations 7 through 10), the noise levels (except in comparison with Location 1) along Upper James Street are all greater than those observed in the CBD. Although residential areas normally have lower noise levels than commercial areas, in the case of the residential areas adjacent to Upper James Street, noise from the traffic along Upper James Street which includes a high percentage of buses and trucks, contributes to the noise environment. However, the noise levels observed here are characteristic of residential areas with a high volume of traffic on a main street or boulevard.

EXISTING VIBRATION LEVELS

The perception of vibration by people has been discussed extensively in the literature, however, most of the criteria are based on the results obtained from steady-state sinusoidal vibration excitation in laboratory environments. Relatively little information is available on the response of humans to low level random vibration or to transient vibration levels. Recently more information on this type of vibration has been obtained from the results of measurements and subjective evaluations of transit train vibration in Toronto, Washington, D.C., San Francisco and Atlanta.

A number of scales for evaluating the effect of vibration on man have been devised. Units such as Pal and Trem have been presented for establishing scales of response to vibration similar to the A-weighted sound level or the various loudness scales which have been used for the determination of subjective response to noise levels. None of the scales have been widely accepted in evaluating human response to vibration levels and, in general, the criteria for response are presented as charts with ranges of response as a function of vibration frequency. As for the subjective response to noise, the human sensitivity to vibration varies with frequency. Therefore, the frequency must be taken into consideration in assessing annoyance due to vibration. A number of studies have indicated that at frequencies above approximately 12 to 16 Hz, the human sensitivity to vibration velocity is not a strong function of frequency. That is, above 12 to 16 Hz, sensitivity to vibration is primarily determined by the velocity amplitude and is relatively independent of frequency. Since the frequency range over which human sensitivity is approximately proportional to velocity amplitude covers the range of principal vibration components from transit trains and since the noise level generated by the vibration of buildings' surfaces is approximately proportional to vibration velocity level, it is appropriate to present vibration criteria and data in terms of velocity level.

Below about 12 to 16 Hz the sensitivity to vibration velocity is somewhat lower. This is characterized in Figure 10 which shows the criteria for maximum acceptable ground-borne vibration from transit trains in residential buildings. The criteria curve is more fully discussed in the Section, Noise and Vibration Criteria. The criteria and curve shape are based to a large extent on the information in the CHABA Publication, "Guidelines for Preparing Environmental Impact Statements on Noise".

The existing exterior vibration sources include automobiles, trucks, buses, underground mechanical equipment, and on a local scale, pedestrians. Most of the vibration sources, except stationary mechanical equipment operating continuously, create transient vibration levels. The observed level of vibration at a particular location is the summation of the vibrations created by all the various sources, near and far. This is analogous to ambient community noise that represents the summation of many noise sources.

The vibration level data were taken simultaneously with, and at the same locations as, the sound level data. Vibration acceleration was measured using a piezoelectric accelerometer, with a signal recorded on one channel of the data tape recorder.

The data were analyzed to obtain a single-number velocity level weighted in such a way to approximate the CHABA weighting shown in Figure 10. To obtain the weighted velocity level from the acceleration data, an electronic integrator and filter with approximately the inverse of the CHABA weighting were used.

Although the CHABA weighting is not a standardized measurement, the resultant weighted velocity level is a good single-number indication of the human response to vibration. Figure 10 indicates that weighted vibration velocity levels below about 69 dB are generally imperceptible or just perceptible as vibration to the average person under normal conditions.

The weighted vibration velocity levels obtained in this manner were statistically analyzed to obtain the same statistical parameters used to describe the existing noise levels; L_{99}, L_{90}, L_{50}, L_{10}, L_1, and L_{EQ}.

Table III presents a complete tabulation of the statistical analysis of the weighted vibration velocity levels observed at each measurement site. In general those locations with the highest noise levels also have the highest vibration levels and vice versa, since in most cases, trucks and buses which produce high noise levels also produce high vibration levels. However, this correlation is not always true since airplanes, motorcycles, and some cars can produce high noise levels but not necessarily high vibration levels.

Review of the data indicates that the lowest vibration levels were observed at Location 6 in the Escarpment area near the proposed north tunnel portal. The low vibration levels here are expected since there are no nearby vibration producing activities.

In the Central Business District (Locations 1 through 5) the highest vibration levels were observed at Location 1 due to the high level of vehicular activity and buses. The vibration levels are somewhat lower at Locations 2 through 5. In the CBD, weighted vibration velocity L_{EQ} ranges from 47 to 55 dB, which when compared with previous environmental vibration studies WIA has done indicates that these vibration levels are typical of those observed in the CBD of other cities (such as Baltimore and Chicago).

In the Mountain area (Locations 7 through 10) the highest weighted vibration velocity level was observed at Location 8. These somewhat higher levels are due principally to the several heavy trucks and some buses which passed by on the east side of the Upper James Street during the time the sample was recorded. The L_1 vibration velocity level of 72 dB indicates that for a period of approximately 6 seconds in 10 minutes the vibration from passing vehicles would be feelable on the sidewalk at this location. Vibration at the other locations should not be feelable as distinct vibration. The weighted vibration velocity L_{EQ} ranges from 42 to 59 dB, which is typical of commercial and residential areas near heavily traveled streets and boulevards.

NOISE AND VIBRATION CRITERIA

There are two sets of appropriate criteria that can be applied to the noise levels produced by the ICTS. The first set is made up of the requirements of the City of Hamilton Noise Control Bylaw (Bylaw No. 79-292 passed in October 1979). The other set that we feel is appropriate are those criteria contained in Section 2-7.6 of the APTA (American Public Transit Association) publication, "Guidelines and Principles for Design of Rapid Transit Facilities." Section 2-7.6 of this APTA Publication presents guidelines for noise and vibration in transit corridor communities. These guidelines as they apply to the proposed ICTS are presented in this section. WIA assisted in preparation of the APTA Guidelines, and we feel that they are appropriate for application to the proposed ICTS, and are in certain situations more restrictive than the requirements of the City Noise Bylaw. In addition, these guidelines specifically address the potential ground-borne noise from transit train operations in subway.

The City of Hamilton Noise Control Bylaw is based on the Model Municipal Noise Control Bylaw developed by the Ontario Ministry of Environment (MOE). Discussion with MOE indicates that they will assess the impact of the ICTS based on the standard which applies to stationary noise sources being introduced into an existing community which is stated in MOE publication NPC 133 as follows:

> " ... for all other types of sound from the source including Quasi-Steady Impulsive Sounds, the predicted one hour equivalent sound level (L_{EQ}) of sound from the source at a point of reception, should not, in any hour of the day, exceed the one hour equivalent sound level (L_{EQ}) of existing industry and existing road traffic measured together as if they constituted a stationary source."

There is no existing industry in the vicinity of the proposed ICTS alignment, thus comparison would be made with the L_{EQ} from existing road traffic. Since road traffic is the predominant noise source in all of the community areas where the ICTS is proposed to operate, a comparison can be made between the L_{EQ} measured in the community and the L_{EQ} anticipated from operations of the ICTS. This comparison is made and discussed in the section, Noise and Vibration Impact Identification.

Criteria for permissible noise levels in nearby buildings and wayside communities due to the transit train operations must be related to the type of community, to the type of occupancy and activity taking place in the building or community and must be related to the prevailing average and peak noise level in the building or community in the absence of new transit system noise. Obviously a passby noise level of a given magnitude will be more objectionable in a quiet park-like environment or in a quiet residential area at night than it will be in a busy commercial area during the day or, in fact, during the night when there are few occupants in a commercial area.

Table IV lists five generalized categories of wayside communities in which transit system facilities are located. The table shows typical daytime and nighttime equivalent sound levels (L_{EQ}) for a one hour period which have been observed in each category of area together with the typical noise levels measured along the proposed ICTS alignment. The measured data has been projected to a full hour with daytime data based on WIA measurements and nighttime data based on MMM/Hatch measurements.

For airborne noise from transit trains, the single event (i.e. single passby) maximum sound level from the trains is the most appropriate means for determining the acceptable wayside noise criteria for the aerial structure operations of the ICTS trains. Table V gives the single event maximum noise level criteria for airborne noise from ICTS trains in each of the area categories as defined in Table IV. The criteria are indicated for several types of buildings or occupancies with the intent of providing consistency and economy in application of the criteria in mixed areas. The criteria presented in Table V are generally referenced to or applied at a point 50 ft from the track centerline. In some cases, where buildings or occupied areas are further from the transit line, the criteria may be referenced to the building or area being considered.

For some types of buildings or occupancies maximum noise level limits should be applied regardless of the community area category. For "quiet" outdoor recreation areas, the single event maximum noise level design goal is 65 dBA. For churches, theatres, schools, hospitals, museums and libraries, the single event maximum noise level design goal is 75 dBA.

Table VI indicates the criteria for airborne noise from transit facilities other than transit trains. Presented are design goal criteria for both transient and steady-state noises from ancillary facilities considering the requirements for minimizing noise exposure during the nighttime hours. At this time it is not known what the ICTS ancillary facilities are or where they will be located. However, Table VI has been included as a guide which can be used during final design.

For underground transit operations, the noise can be transmitted as vibration through the ground and transformed into sound in buildings by radiation off the vibrating room surfaces. The sound in nearby buildings due to underground operations takes the form of a very low frequency rumble, since higher frequency vibrations are attenuated very rapidly in passing through the soil, or in making the transition from soil to building structure.

Based on the typical noise levels encountered in transit corridor communities and based on considerations of noise intrusion or acceptability for different types of occupancies and building uses, a set of criteria has been determined defining the design goal maximum levels for ground-borne noise from transit trains, as it is perceived in various types of buildings. This set of criteria is the same as that included in the APTA Guidelines, and is appropriate for application to the underground operations of the ICTS. Table VII presents these criteria. Section (1) presents the criteria for maximum ground-borne noise level for various types of buildings. Section (2) presents the criteria for various types of sleeping areas.

The perception of a train passing by in a subway close to a building is almost exclusively acoustic. The actual vibration levels are, in all but the most extreme cases, well below the level of tactile perception, but as previously discussed, the acoustic noise radiated from the vibration of building surfaces can be perceived under some conditions of proximity to the subway, efficient transmission, and low background noise levels.

In the rare instance where vibration is perceptible, then the noise induced from the vibration would be sufficient to require mitigating measures to reduce the noise. These measures would also reduce the vibration to an imperceptible level. Generally, only in cases where optical, electrical or electronic and not noise (such as seismic bank vault alarms, electron microscopes or computer equipment), are vibration criteria alone useful in preventing intrusion from transit train passbys. Vibration with a velocity level below the criteria shown on Figure 10 will not adversely affect vibration sensitive equipment.

The vibration criteria shown on Figure 10 has been presented to allow a direct comparison between the existing ambient vibration velocity levels and those anticipated from the ICTS trains. Figure 10 shows the criteria or range of levels considered at this time to be the maximum acceptable ground-borne vibration from transit trains in residential buildings. As briefly discussed previously, the criteria are based on the CHABA Publication, "Guidelines for Preparing Environmental Impact Statements on Noise", the ISO document, "Guide to the Evaluation of Human Exposure to Whole Body Vibration", with the proposed addendum 2, "Vibration and Shock Limits for Occupants in Buildings", and the results of measurements and subjective evaluations of transit train vibration in Toronto, San Francisco, Washington, D.C. and Atlanta. These criteria are still in the development stage and may be revised as more objective and subjective data are obtained. However, it has been determined that vibration from trains of levels within and above the range shown create strong reaction on the part of residents and any revisions are likely to be downward.

As discussed previously and reiterated here, a criterion with less resolution but which can give acceptable results is the evaluation of the "weighted overall" vibration velocity level. Using a weighting curve as shown by the shape of the curves on Figure 10, the overall weighted velocity level can be determined. In order for the vibration to be acceptable, the weighted vibration velocity level should be less than:

69 to 74 dB re 1.0 micro-in/sec.

This can be interpreted as:

* Less than 69 dB should be acceptable.

* More than 74 dB is likely to be unacceptable.

* 69 to 74 dB may or may not be acceptable.

PROJECTED NOISE AND VIBRATION FROM THE ICTS SYSTEM

As indicated in the Introduction and Summary, the prediction models for wayside noise and vibration are based principally upon the noise and vibration data taken by Metro Canada Ltd. and the Toronto Transit Commission (TTC) at the ICTS prototype test track in Kingston, Ontario. In addition, we have used data obtained from other light and heavy rail rapid transit systems to assist in formulating a prediction model which is as accurate as possible based on the currently available data.

The baseline data from the operating ICTS vehicle at the Kingston, Ontario test track includes, (1) wayside noise measurements made at 15 m both at guideway height and 1.5 m above the ground by MCL, Kingston and reported in a memo to H. Ledsham from G. Unsworth and L. Gray, and (2) extensive wayside noise and vibration measurements made by the Toronto Transit Commission (TTC) of trains on both the at-grade and aerial portions of the ICTS structure and reported in the Toronto Transit Commission Engineering Department Research Section, Research Memo #693, dated June 25, 1981. Since there is no underground test section at Kingston, vibration data from the at-grade and aerial structure test sections in conjunction with vibration data obtained at underground sections of other transit systems have been used to estimate the level of ground-borne vibration from the ICTS when traveling in the underground section of the proposed alignment.

Noise

Except for noise from ancillary facilities, the noise from the proposed ICTS will be from the trains operating on aerial structure. Although the train passbys will result in considerably lower noise levels than diesel buses and those associated with even the most modern transit systems, the train passbys will not be unnoticeable. However the noise produced by a train passby should be entirely acceptable to the wayside community. This acceptability aspect is discussed in the Section, Noise and Vibration Impact Identification.

Table VIII indicates the baseline noise data that have been utilized in this study. These noise levels are for two car trains, which is the proposed normal train length, operating on aerial structure at a receiver distance of 15 m from the structure centerline. The baseline noise data assumes that both wheels and rails are smooth, without any wheel flats. Table VIII indicates that there is a significant difference in noise level based on whether the receiver is on the ground or at guideway height. This is due principally to the parapet wall which is part of the aerial structure, and in the case of a far track train (in the dual guideway areas) the difference is also due to the near track structure which contributes to additional noise shielding.

Vibration

Projected levels of typical ground-borne noise and vibration inside buildings along the proposed route of the Hamilton-Wentworth ICTS were computed using vibration data obtained in measurements at the Kingston test facility and prediction models developed from existing rapid transit systems. The prediction models account for the fact that ground-borne vibration from the ICTS tends to be much lower than for modern heavy-rail transit systems at the same distances and for similar vehicle operations.

The measured data obtained at the Kingston facility was for operation at-grade and on aerial structure, whereas the Hamilton system will consist of subway and aerial structure. The vibration and noise levels predicted for the subway portion of the Hamilton system account for the difference in ground vibration levels between at-grade and subway operation. However, no measured data is available for ICTS subway operation and only limited data is available for at-grade operation. Also soil conditions and underlying geologic strata differences most likely exist between

Hamilton and Kingston. For these reasons the actual vibration and noise levels, due to ground-borne vibration, may vary somewhat from those predicted in this present evaluation.

Noise due to ground-borne vibration emanating from transit train operations on aerial structures is, except in very unusual circumstances, overshadowed by airborne noise from the transit vehicle. Consequently the major potential for impact due to ground-borne vibration along the aerial portion of the Hamilton ICTS route is due to building vibration. Based on the measured vibration, obtained at the Kingston test facility, and typical soil/structure coupling, the predicted in-house, range of vibration velocity level is 45 to 55 dB (re: 10^{-6} in/sec), at 8 m from an ICTS aerial structure column footing, for a 2-car train traveling at 72 kph. For a 4-car train the vibration velocity level is not anticipated to increase more than 1 or 2 dB, only the duration of the level will be different. It should be noted that this predicted velocity level assumes that the aerial structure at Hamilton will not be significantly different from that at the Kingston facility.

Both building vibration and structurally radiated noise due to ground-borne vibration from subway operation can have a potential for impact because of the absence of airborne noise from transit vehicles in the case of subway operation. Due to the wide variation in possible distances from the subway tunnel of the Hamilton system and in possible types of building construction, seven specific sites, which were considered to be representative of buildings potentially impacted by subway operations along this portion of the proposed route, were examined. Difference in tunnel depth (the T/R is at a maximum depth of approximately 115 ft at the escarpment) and maximum anticipated train speed at specific points on this portion of the route were included in the analysis.

Table IX indicates the predicted in-house vibration and noise levels at each of the sites analyzed. It should be noted that the levels indicated are based on a range of possible building construction types at each of the sites and assumptions pertaining to the properties of the rock in which the subway tunnel at Hamilton will be founded. Actual levels may vary somewhat from those shown in Table IX, but should be no more than 4 to 6 dB greater. During final design, noise (and also vibration) sensitive buildings along this part of the proposed route should be identified and examined in closer detail to determine specific impact once the final alignment and depth of the structure are determined.

In addition to the interior vibration levels predicted in Table IX for subway operation, ground surface velocity levels were predicted at the WIA ambient noise and vibration measurement Location numbers 7 and 8. This was done in order to provide a means of comparison between the existing vibration levels and those expected from subway operation. The predicted maximum weighted velocity level at Location 7 is 52 dB and the corresponding level at Location 8 is 55 dB.

NOISE AND VIBRATION IMPACT IDENTIFICATION

In order to determine if the implementation of the ICTS will have any adverse noise and vibration impact on the Hamilton-Wentworth community, it is necessary to compare the projected noise and vibration levels expected from the system with the appropriate noise and vibration criteria which have been previously presented. The noise and vibration levels expected at the noise and vibration sensitive buildings have been determined using the alignment location and distances indicated in Figures 1 through 9. If the final alignment location should vary from that shown on Figures 1 through 9, the relative impact of the ICTS may change.

Airborne Noise

On a general comparison basis, the passby noise from ICTS trains on aerial structure will meet the criteria presented. In order to indicate this acceptability in more detail and to ascertain that there will be no adverse noise impact in buildings near the alignment, noise sensitive structures and areas have been identified. A listing which summarizes the structures and areas considered is shown in Table X. Note that these locations are not the same as the noise and vibration survey locations.

Table XI shows the expected maximum noise levels from a single 2-car train passby at each of the noise sensitive locations identified in Table X. In addition the appropriate criterion for each location is indicated. A receiver location at guideway height and 1.5 m above the ground are reported in order to assess the impact at the 2nd story and upper floors of apartment buildings as well as for a receiver standing on the ground. Table XI indicates that for both receiver positions, the criterion is achieved at each of the noise sensitive locations.

Table XII shows the expected maximum hourly equivalent sound level (L_{EQ}) at each of the noise sensitive locations based on peak hour operations and off-peak hour operations. Peak hour operations will have 3 minute headways between 0700 and 0900 hours and between 1600 and 1800 hours. Off-peak hour operations will have 5 minute headways between 0530 hours and 0130 hours except for the peak hour operations. For both peak and off-peak operations, the train length will be two cars. The expected maximum equivalent sound level has been calculated for two receiver positions, 1.5 m above the ground and at guideway height. The L_{EQ} criteria have been determined from the data obtained by MMM/Hatch Associates. The criteria are the minimum equivalent sound levels measured during the 24-hour noise surveys (MMM/Hatch locations #9, 10 & 11) which occurred during the period when the ICTS would be operating. This period was generally between 0100 and 0200 hours. Although lower equivalent sound levels were often observed between 0200 and 0500 hours, the ICTS trains will not be operating during this time period. Since there were only three successful 24-hour noise surveys performed along the proposed ICTS alignment, we have also utilized the spot-check late night noise measurements performed by MMM/Hatch at their locations #9b, 10d and 12a. Although full 24-hour noise surveys would be needed to determine if these noise levels are appropriate as criterion, they have been utilized as the best information available at this time. It should be noted that during the off-peak hours at any of the identified noise sensitive locations the minimum measured equivalent sound level would have to be less than 48 dBA for ICTS operations to exceed the requirements of the City Noise Bylaw. Thus even if the actual minimum equivalent sound level at some of the noise sensitive locations is lower, it is still anticipated that the actual minimum equivalent sound level will be greater than that produced by the ICTS trains and the requirements of the City Noise Bylaw will be satisfied.

Although the noise levels that will be produced by the ICTS trains will meet the applicable noise criteria without the use of any special noise reduction features, it is recommended that during final design further analysis of the noise levels produced by the ICTS trains at the second and third story apartment units of the building located at Hughson and Young Streets since some of these apartments have balconies which will directly face the alignment. Further analysis is also recommended of the noise levels produced by the ICTS trains where the structure crosses over a corner of the Canadian Football Hall of Fame building.

Ground-borne Noise and Vibration Impact

Potential noise impact due to transit train operation on aerial structure is, except in unusual situations, caused by airborne noise emanating from the transit vehicle. Therefore, for trains operating on aerial structure, it is only necessary to determine the impact of vibration due to motion transmitted to buildings from the guideway columns through the intervening soil. The predicted range of maximum, weighted velocity level is 45 to 55 dB inside a building at 8 m from a column footing. This corresponds to a single, 2-car train passby which may last as long as 5 seconds. For a train passby frequency of 6 trains/hour, a vibration level of this duration, corresponds to approximately an L_1 value. Since the maximum expected vibration velocity level is 55 dB, the vibration level at 8 m is considerably below the criteria level of 69 dB as indicated on Figure 10.

Based on this evaluation, buildings at a distance of 10 m from guideway column footings will obviously not be exposed to any adverse vibration impact from ICTS operation on the elevated portion of the route. However due to possible variations, in soil conditions and underlying geologic strata, between the Kingston test facility and Hamilton, actual vibration levels at Hamilton may be somewhat higher than those measured at Kingston. During final design, guideway column footings which are located closer than 10 m to a building, should be studied in more detail to determine more specifically the potential for adverse impact due to vibration, and the possible need for mitigating measures in such instances.

Along the subway portion of the proposed ICTS route there will obviously be no airborne noise emanating from the transit vehicles, consequently both ground-borne noise and vibration due to transit train operations along this portion of the proposed route must be considered. The residential area along Upper James Street can be classified as "average urban". A comparison of the predicted indoor noise levels, due to vibration from a 2-car train passby, at various typical sites shown in Table IX, with the appropriate criteria for ground-borne noise shown in Table VII indicate that the predicted levels are within the acceptable range, except at Site 7 which is in the vicinity of the proposed Fennell Street Station.

The expected noise levels due to ground-borne vibration at Site 7 can be considered marginally acceptable due to the assumptions inherent in predicting levels based on the very limited measured data available at this time (eg. no subway data for the ICTS). Data which is available at the final design stage will allow a more definite determination of expected levels at specific buildings.

A comparison of the predicted vibration levels for the subway region with the criteria of 69 dB indicates that the expected levels are within acceptable limits except at Site 7 as was the case with the predicted ground-borne noise levels. Since, the vibration and noise levels are expected to be marginally acceptable in this area, it is strongly recommended that, during the final design phase more detailed consideration be given to predicting any potential for adverse impact in this area of the proposed ICTS route where the subway tunnel depth is shallow. In the event that such an evaluation determines a need for special design features, possible techniques for reducing ground-borne vibrations are discussed under Possible Noise and Vibration Control Measures.

COMMUNITY AREAS WITH THE POTENTIAL FOR NOISE REDUCTION

If the proposed ICTS is actually implemented, there will be significant changes in the bus traffic pattern between the CBD and Mountain areas. Apart from some potential decrease in automobile traffic between these two areas, the only significant decrease will involve diesel buses.

At a distance of 50 ft, a typical diesel bus passby produces approximately 86 dBA on acceleration and approximately 80 to 82 dBA when cruising at about 30 mph. This is a significant noise level particularly when compared with the passby noise levels anticipated from the operation of the ICTS trains under similar conditions. Along with trucks and motorcycles, buses generally produce the highest vehicular noise levels and depending on the makeup of traffic (i.e. percentage of trucks and buses) can predominate the peak noise levels and thus the resulting equivalent sound level (L_{EQ}) in the community. Thus a significant reduction in the number of bus passbys can result in a corresponding significant reduction in the equivalent sound level.

Correspondingly a significant increase in the number of bus passbys can significantly increase the equivalent sound level.

If bus passbys create the predominant peak noise in an area, (i.e. there are few trucks, motorcycles or noisy cars), then reducing the number of bus passbys by one-half during an hour period would reduce the hourly L_{EQ} by 3 dBA. A further reduction by another half would give another 3 dBA reduction in the equivalent sound level. The equivalent noise level would continue to decrease until other noise sources predominate and keep the level from decreasing further.

Thus, in order to quantify the reduction of equivalent sound level due to a decrease in the number of buses, it is necessary to know what the traffic composition is in an area. For example, in the Jolley Cut area the peak hour bus volume will decrease from 93 to 12 buses after the ICTS is implemented. If the buses were the only noise source here, then there would be a resulting drop of 8 dBA in the peak hour equivalent sound level. However, from a more realistic perspective, this decrease in bus traffic will probably not decrease the equivalent sound level by this amount. However, based on other studies of this nature, this decrease in the number of buses during the peak hour should result in at least a 3 dBA drop in the sound equivalent level and probably even a greater amount. It should be noted that this decrease in equivalent sound level for other hourly periods would probably be less, since except for streets with a large volume of bus traffic throughout the day, buses do not predominate the noise.

It can be concluded that in several areas which now have extensive bus traffic, based on proposed bus rerouting, there is the potential for significant community noise reduction. For example, in the Gore Park, John Street, James Street and Jolley Cut areas, the peak hour equivalent sound level (L_{EQ}) should be reduced by at least 3 dBA.

COMMUNITY AREAS WITH THE POSSIBILITY OF INCREASED NOISE LEVELS

As discussed in this report, implementation of the ICTS will not increase the equivalent sound level in the areas where the trains will operate. Also, as previously disucssed, if the proposed ICTS is actually implemented, there will be significant changes in the bus traffic pattern between the

CBD and Mountain areas and in the Mountain area itself. Apart from some potential increase in automobile traffic for automobiles travelling to and from the two stations proposed for the Mountain area, the only projected significant increase in traffic will involve diesel buses in the vicinity of the two stations proposed for the Mountain area.

As discussed in the section, Community Areas With the Potential for Noise Reduction, if bus passbys create the peak noise in an area, then reducing the number of bus passbys by one-half during an hour period would reduce the hourly L_{EQ} by 3 dBA. Conversely, if bus passbys create the predominant peak noise in an area, then doubling the number of bus passbuy during an hour period would increase the hourly L_{EQ} by 3 dBA. As with a decrease in the number of bus passbys in area, in order to quantify the effect of increasing the number of buses, it is necessary to know what the traffic composition is in an area.

Currently it is proposed that the number of buses near the two stations in the Mountain area will have the following changes during the peak hour: on Fennell Avenue west of Upper James Street there will be essentially no change, on Fennell Avenue east of Upper James Street the number of buses will increase from 6 to 18, on Mohawk Road west of Upper James the number of buses will increase from 4 to 15 and on Mohawk Road east of Upper James the number of buses will increase from 4 to 10. The maximum change involves almost four times as many buses, which if the buses predominated the peak noise level would result in an increase in the peak hour L_{EQ} of approximately 6 dBA. However the increase should be less since with relatively few buses existing now, the buses do not predominate the existing noise environment which already has a considerable volume of truck and automobile traffic. The increase in bus volume would not increase the peak hour L_{EQ} by 6 dBA. A more realistic increase in the peak hour L_{EQ} would be 3 or 4 dBA at most.

It can be concluded that in the immediate areas around the two stations in the Mountain area, along Mohawk Road and on Fennell Avenue east of Upper James Street, the predicted maximum increase in the peak hour equivalent sound level (L_{EQ}) will be 3 or 4 dBA.

POSSIBLE NOISE AND VIBRATION CONTROL MEASURES

As indicated by the analyses performed in the present impact evaluation, the resulting noise and vibration levels due to operation of the ICTS along the proposed Hamilton-Wentworth route, are expected to have no adverse impact on the wayside community through which it will pass. However, in certain locations the impact due to ICTS operations may be only marginally acceptable although all applicable criteria have been satisfied. These areas have been identified in the section, Noise and Vibration Impact Identification.

During the final design of the ICTS for Hamilton, should further analysis of specific areas of the route indicate the need for noise and vibration control measures, the following measures are those most commonly employed to reduce noise and vibration from modern transit systems.

Sound Barrier Wall

Where special circumstances warrant, sound barrier walls have been employed successfully along the route of rapid transit systems to reduce wayside levels of airborne noise from transit vehicle operations. Typical sound barrier walls for rapid transit system aerial structures consist of a concrete slab which is at least high enough to shield the impacted portion of ground or building from a direct line-of-sight with the the transit vehicle undercarriage. For reasonable wall heights the wall alone does not eliminate sound which is reflected from the inside of the wall to the transit vehicle body side and back towards the impacted building, therefore sound absorptive treatment is often applied to the inside surface of the wall to control this reflected noise.

The guideway structure, as proposed, will include a parapet wall which is an integral part of the guideway beam and is approximately 22 inches high. In switch areas the parapet will be 36 inches high. The height of this wall will have a definite effect on noise levels on the ground. For buildings close to the elevated structure, which are higher than the guideway parapet wall a more substantial sound barrier wall may be necessary. Examples of some existing sound barrier walls are illustrated in Figure 11. The typical height for rapid transit system sound barrier walls is from 4 to 5 ft, however for particularly close buildings which are at guideway height a higher barrier wall may be necessary.

Based on calculations using the characteristics of the ICTS, a barrier height of 5 ft would reduce the A-weighted noise level by 8 to 10 dB at a distance of 30 ft from the track and at a height equal to that of the bottom of a transit vehicle on the guideway. At the same distance (30 ft) from the guideway but at a greater height the effectiveness of a 5 ft sound barrier would be somewhat reduced. At the same time the distance between the noise source and observer increases with increasing height which would mean a lower noise level to start with in the case of no barrier wall. The actual height of a sound barrier wall (if found to be necessary) should be determined in the final design phase when more definite details are known.

Special Rail Support Systems

The proposed fastener system (Hixon or equivalent) for the ICTS at Hamilton is referred to as direct fixation resilient fastener. Where it is necessary to control ground-borne vibration from at-grade or subway transit operation there exist two commercially available methods for reducing transmitted vibration levels at the rail. The two systems are the "Cologne Egg", developed by the Cologne (West Germany) Transport Authority, and the RS-STEDEF ballastless track system.

The "Cologne Egg" is a recently developed resilient-direct-fixation fastener of non-conventional design. With this fastener, low vertical stiffness has been obtained without sacrificing lateral stability. It is reputed to have excellent vibration isolating characteristics, however at this point the Cologne Egg has not been used on any North American transit system.

The RS-STEDEF ballastless track system is a two-block concrete tie system, with the ties supported directly on the invert by elastomer boots. This system reduces ground-borne noise and vibration levels through the isolating effect of the concrete tie mass supported on soft pads. At frequencies above the resonance of the concrete tie/resilient pad system, the vibration reduction is quite large and can reach as much as 9 dB in some octave bands.

There exists other track fastener systems, but the two mentioned above have the greatest potential for providing significant reduction in ground-borne vibration. Other direct fixation resilient fasteners commonly available may provide some reduction in ground-borne vibration, but probably not enough to warrant consideration, without a special design specifically for the ICTS system.

Floating Slab Vibration Isolation

Floating slabs, though relatively expensive, are extremely effective in controlling ground-borne noise and vibration. The actual design of the floating slab is dependent on particular characteristics of the system. In general terms, the two designs being used on many of the new transit systems are: the lightweight continuous floating slab, and the discontinuous floating slab.

The vibration isolation effectiveness of several floating slabs has been evaluated at several rapid transit systems. These include the continuous slab used at the Washington Metro (WMATA) structures and the discontinuous or double-tie floating slab used at Toronto Transit Commission (TTC) and Metropolitan Atlanta Rapid Transit (MARTA). The results of measurements at WMATA and MARTA show that the resulting vibration reduction for both above 31.5 Hz are essentially the same.

At TTC, measurements indicate that above 31.5 Hz the isolation system is better than at WMATA and MARTA. The variation in effectiveness may be due to any number of factors, but differences in transit vehicles between the systems are the most likely causes. This factor indicates the need for a detailed analysis to determine the specific design of any floating slab which may be used in special circumstances.

TABLE I LOCATIONS USED FOR EVALUATION OF THE VIBRATION AND NOISE ENVIRONMENT ALONG THE PROPOSED ICTS ALIGNMENT

Location Number	
1	On sidewalk at the southeast corner of the intersection of King and MacNab Streets.
2	On sidewalk at the southwest corner of the intersection of Jackson and Catharine Streets.
3	On sidewalk at the southeast corner of the CFL Hall of Fame building.
4	On sidewalk at the northeast corner of the Church located at the intersection of Augusta and Hughson Streets.
5	On sidewalk at the southeast corner of the intersection of Forest and Hughson Streets.
6	On the footpath leading up the Escarment east of the Scout House near the proposed tunnel portal.
7	On sidewalk at the southeast corner of the intersection of Upper James Street and Inverness Avenue.
8	On sidewalk at the southeast corner of the intersection of Upper James Street and Empress Avenue.
9	On sidewalk at the southwest corner of the intersection of Upper James Street and Monarch Road, across from the Shopping Center.
10	On sidewalk at the southeast corner of the intersection of Upper James Street and South Bend Road.

TABLE II EXTERIOR NOISE ENVIRONMENT OBSERVED AT TEN LOCATIONS ALONG THE PROPOSED ICTS ALIGNMENT DURING THE DAYTIME — AUGUST 27, 1981

Location	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
1	61 dBA	63 dBA	69 dBA	72 dBA	78 dBA	70 dBA
2	57	59	63	69	75	66
3	54	55	57	64	68	60
4	52	53	56	64	72	61
5	53	54	57	62	67	59
6	42	44	48	51	56	49
7	51	57	65	72	80	69
8	53	57	66	75	81	71
9	50	55	61	68	77	66
10	52	58	65	71	78	68

TABLE III MEASURED EXTERIOR VIBRATION VELOCITY LEVELS[1] AT TEN LOCATIONS ALONG THE PROPOSED ICTS ALIGNMENT DURING THE DAYTIME — AUGUST 27, 1981

	dB re 1 mico in/sec					
Location	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
1	48	50	53	58	64	55
2	45	46	48	51	57	49
3	45	47	50	54	61	52
4	40	42	46	50	61	50
5	39	42	45	50	54	47
6	30	34	37	42	50	40
7	33	36	40	44	51	42
8	35	39	47	59	72	59
9	37	41	45	51	63	52
10	36	39	44	51	60	49

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[1] Corrected for human perception curve (see text)

TABLE IV GENERAL COMMUNITY CATEGORIES ALONG TRANSIT SYSTEM CORRIDORS

		Daytime Hourly Equivalent Sound Levels (L_{eq})		Nighttime Hourly Equivalent Sound Levels (L_{eq})	
Category	Area Description	Normal Expected Range	Measured Along ICTS Alignment	Normal Expected Range	Measured Along ICTS Alignment
I	Low Density urban residential, open space park, suburban residential or quiet recreational area. No nearby highways or boulevards.	45-55 dBA	49 dBA	40-50 dBA	--
II	Average urban residential quiet apartments and hotels, open space, suburban residential, or occupied outdoor area near busy streets.	50-60 dBA	--	45-55 dBA	46 dBA
III	High Density urban residential, average semi-residential/commercial areas, parks, museum, and non-commercial public building areas.	55-65 dBA	59-71 dBA	50-60 dBA	50-65 dBA
IV	Commercial areas with office buildings, retail stores, etc., primairly daytime occupancy. Central Business Districts.	65-75 dBA	60-70 dBA	60-70 dBA	65 dBA
V	Industrial or Freeway and Highway Corridors	Over 65 dBA	--	Over 65 dBA	--

Normal Expected Range is based on field data obtained in many community areas in the U.S.A. and Canada.

TABLE V CRITERIA FOR MAXIMUM AIRBORNE NOISE FROM TRAIN OPERATIONS

Community Area Category	Single Event Maximum Noise Level Criteria: Single Family Dwellings	Multi-Family Dwellings	Commercial Buildings
I Low Density Residential	70 dBA	75 dBA	80 dBA
II Average Residential	75	75	80
III High Density Residential	75	80	85
IV Commercial	80	80	85
V Industrial/Highway	80	85	85

Criteria are based on APTA Guidelines (see text).

TABLE VI CRITERIA FOR NOISE FROM TRANSIT SYSTEM ANCILLARY FACILITIES

Community Area Category	Maximum Noise Level Criteria	
	Transient Noises	Continuous Noises
I Low Density Residential	50 dBA	40 dBA
II Average Residential	55	45
III High Density Residential	60	50
IV Commercial	65	55
V Industrial/Highway	75	65

These criteria should be applied at 50 ft from the shaft outlet or other ancillary facility or should be applied at the setback line of the nearest building or occupied area, whichever is the shorter distance. Transient criteria apply to short time duration events such as train passby noise transmitted from vent shaft openings. Continuous criteria apply to noises such as fans, cooling towers, or other long duration noises except electrical transformer hum. The criteria for transformer noise or hum should be 5 dBA less than given in the Table.

Criteria are based on APTA Guidelines (see text).

TABLE VII CRITERIA FOR MAXIMUM GROUND-BORNE NOISE FROM TRAIN OPERATIONS

[1] Various Types of Rooms or Buildings Located Near The Subway Structure

Type of Building or Room	Ground-Borne Passby Noise Criterion
Concert Halls and TV Studios	25 dBA
Auditoriums and Music Rooms	30 dBA
Churches and Theaters	35 dBA
Hospital Sleeping Rooms	35-40 dBA
Courtrooms	35 dBA
Schools	40 dBA
University Buildings	35-40 dBA
Offices	35-40 dBA
Commercial Buildings	45-55 dBA

[2] Various Types of Residential Buildings

		Maximum Single Event Ground-Borne Noise Level		
Community Area Category		Single Family Dwellings	Multi-Family Dwellings	Commercial (Hotel/Motel) Buildings
I	Low Density Residential	30 dBA	35 dBA	40 dBA
II	Average Residential	35	40	45
III	High Density Residential	35	40	45
IV	Commercial	40	45	50
V	Industrial/Highway	40	45	55

Criteria are based on APTA Guidelines and measurements at other transit systems (see text).

TABLE VIII PROJECTED NOISE LEVELS AT 15 m (50 FT) FROM 2-CAR ICTS TRAINS OPERATING ON AERIAL STRUCTURE

Speed	Train on Near Track		Train on Far Track	
	1.5 m Above Ground	At Guideway Height	1.5 m Above Ground	At Guideway Height
15 mph (24 km/h)	53-54 dBA	57-58 dBA	47-48 dBA	54-55 dBA
20 mph (32 km/hr)	55-56	59-60	48-49	56-57
25 mph (40 km/h)	57-58	61-62	49-50	58-59
30 mph (48 km/h)	59-60	63-64	50-51	60-61
35 mph (56 km/h)	61-62	65-66	51-52	62-63
40 mph (64 km/h)	63-64	67-68	53-54	64-65
45 mph (72 km/h)	65-66	69-70	55-56	66-67

Data are based on measurements made using a single vehicle at three speeds by MCL and TTC at the Kingston Test Facility. That data has been projected to 2-car trains at the speeds indicated in the table.

TABLE IX NOISE AND VIBRATION LEVELS DUE TO SUBWAY OPERATION AT HAMILTON-WENTWORTH

Site	Type of Building	Horizontal Distance to Near Track (ft)	Predicted Noise Level (dBA)	*Predicted Velocity Level (dB re 10^{-6} in/sec)
A	Convent	100	25-30	50-55
B	Commercial	35	30-40	45-60
C	House	20	30-35	50-55
D	Commercial	15	30-40	50-65
E	Public School	345	15-20	30-40
F	Commercial	25	25-35	45-60
G	Commercial	25	35-45	55-70

*CHABA weighting - typical existing vibration velocity levels are given in Table III

TABLE X NOISE SENSITIVE STRUCTURES AND AREAS ALONG THE PROPOSED ICTS ALIGNMENT

Noise Sensitive Location Number	Description
1	Houses on Upper James Street between Wembly Road and Richwell Road
2	House on east side of James Street/Mountain Road north of Aberdeen Avenue
3	House on south side of Freeman Place east of the proposed alignment
4	Large houses on west side of James Street,S. between Charlton Avenue, W. and St. James Place
5	Medical Offices on Hughson Street between Forest Street and Charlton Avenue
6	Apartment buildings on Hughson Street between Young and Forest Streets
7	Church at the corner of Hughson and Augusta Streets
8	Office buildings on Hughson Street between Beckley and Augusta Streets
9	CFL Hall of Fame building on Jackson Street
10	Restaurant on Catharine Street between Jackson and Hughson Streets

TABLE XI EXPECTED MAXIMUM NOISE LEVELS AND CRITERIA FOR 2-CAR ICTS TRAIN PASSBYS

Noise Sensitive Location Number*	Expected Maximum Noise Level		Criterion
	1.5 m Above Ground	At Guideway Height	
1	63 dBA	67 dBA	75 dBA
2	68	72	75
3	61	64	70
4	55	59	75
5	55	59	75
6	58	62	80
7	57	61	75
8	54	58	85
9	64	68	85
10	59	63	85

*These locations are *not* the same as the noise and vibration measurement locations.

Criterion are based on APTA Guidelines given in Table V.

URBAN DOCUMENTATION CENTRE
RESEARCH UNIT FOR URBAN STUDIES
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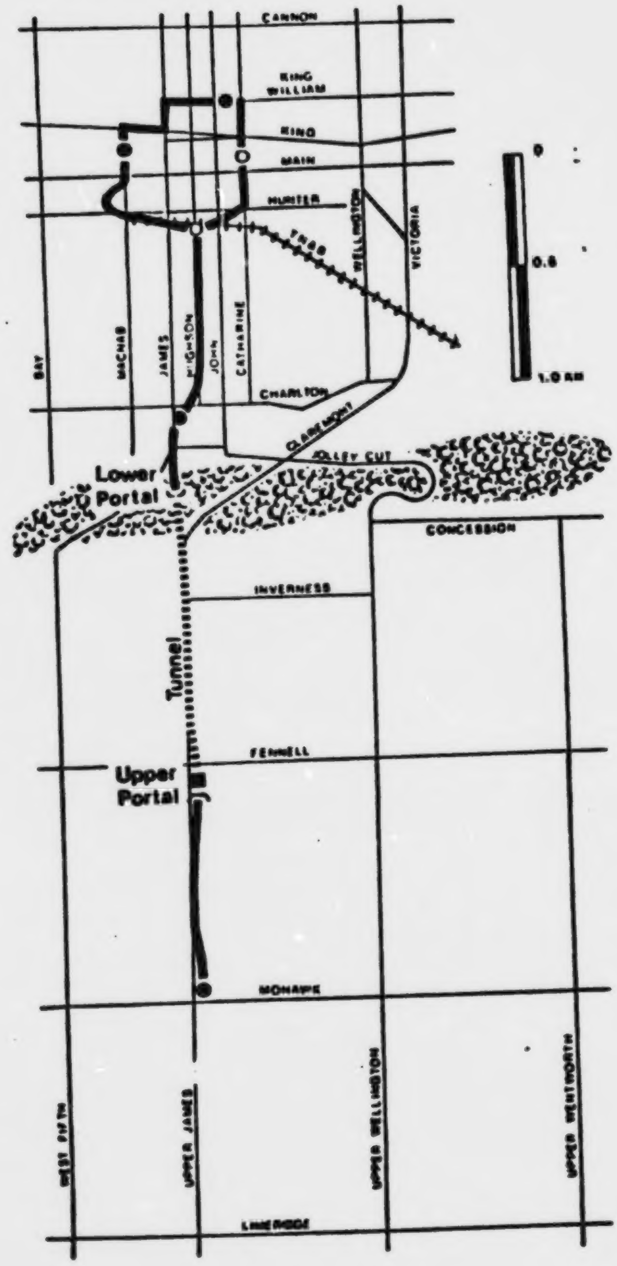
TABLE XII EXPECTED MAXIMUM HOURLY EQUIVALENT SOUND LEVELS (L_{eq}) FROM 2-CAR ICTS TRAINS AND CITY NOISE BYLAW CRITERION

	Expected Maximum Equivalent Sound Level (L_{eq})				
	Peak Hour		Off-Peak Hour		
Noise Sensitive Location Number[1]	1.5 m Above Ground	At Guideway Height	1.5 m Above Ground	At Guideway Height	L_{eq} Criterion[2]
1	42 dBA	46 dBA	39 dBA	43 dBA	50 dBA front yard 46 dBA back yard
2	48	51	45	48	54
3	40	43	37	40	54
4	35	39	33	37	61
5	38	52	36	40	50
6	40	44	38	42	50
7	39	43	37	41	50
8	37	41	35	39	50
9	45	49	43	47	65
10	42	46	40	44	65

[1] These locations are *not* the same as the noise and vibration measurement locations.

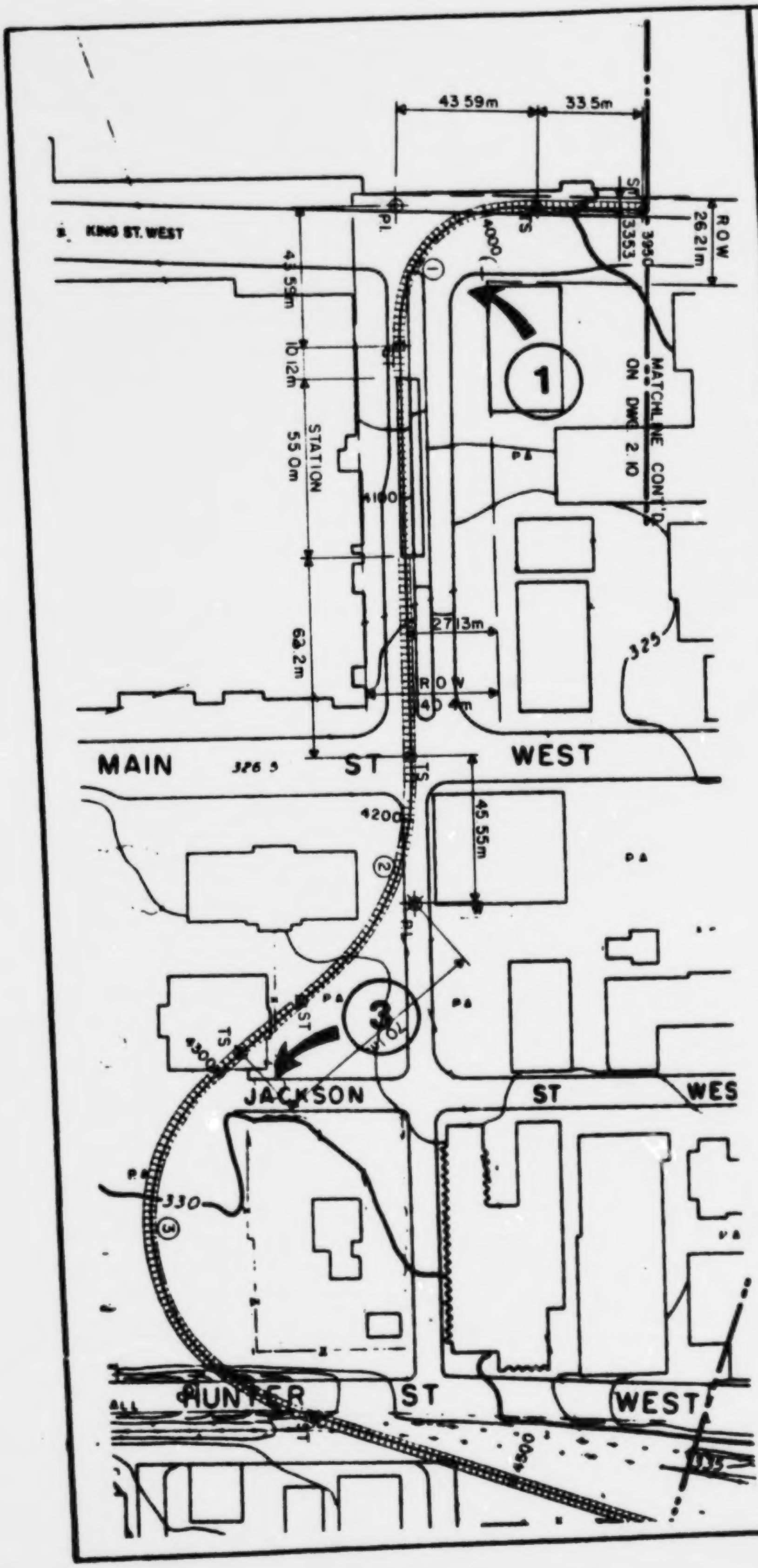
[2] The criteria are based on the nighttime noise measurements performed by MMM/Hatch (see text).


CANNON
KING WILLIAM
KING
MAIN
HUNTER
WELLINGTON
VICTORIA
BAY
MACNAB
JAMES
HUGHSON
JOHN
CATHARINE
CHARLTON
CLAREMONT
JOLLEY CUT
Lower Portal
CONCESSION
INVERNESS
Tunnel
FENNELL
Upper Portal
MOHAWK
WEST FIFTH
UPPER JAMES
UPPER WELLINGTON
UPPER WENTWORTH
LIMERIDGE
0
0.5
1.0 KM
● Elevated Station
■ Underground Station
○ Optional Station

HAMILTON-WENTWORTH
RAPID TRANSIT PROJECT

FIGURE 1

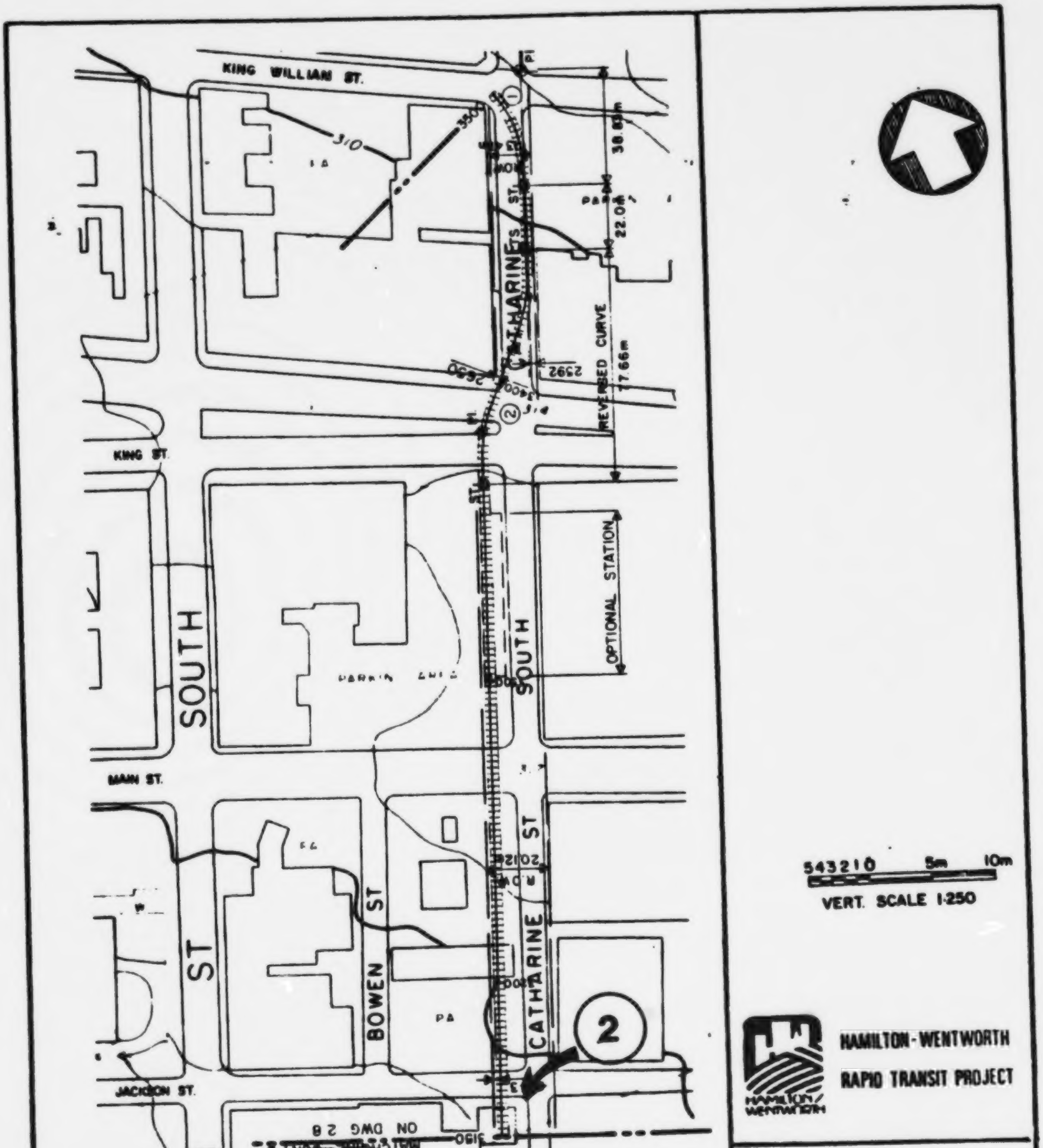
RAPID TRANSIT ROUTE
SELECTED BY COUNCIL
ON JULY 31, 1981
FOR FURTHER STUDY


43.59m
33.5m
KING ST. WEST
P.I.
TS
4000
SC
3353
3950
ROW
26.21m
43.59m
1
MATCHLINE CONT'D ON DWG. 2.10
10.12m
STATION
55.0m
4100
P.A
27.13m
ROW
40.4m
63.2m
325
MAIN
326.5
ST
WEST
TS
4200
45.55m
2
P.A
P.I.
3
ST
TS
4300
JACKSON
ST
WES
330
3
HUNTER
ST
WEST

543210 5m 10m
VERT. SCALE 1:250

HAMILTON-WENTWORTH
RAPID TRANSIT PROJECT

FIGURE 2
MEASUREMENT
LOCATIONS 1 AND 3

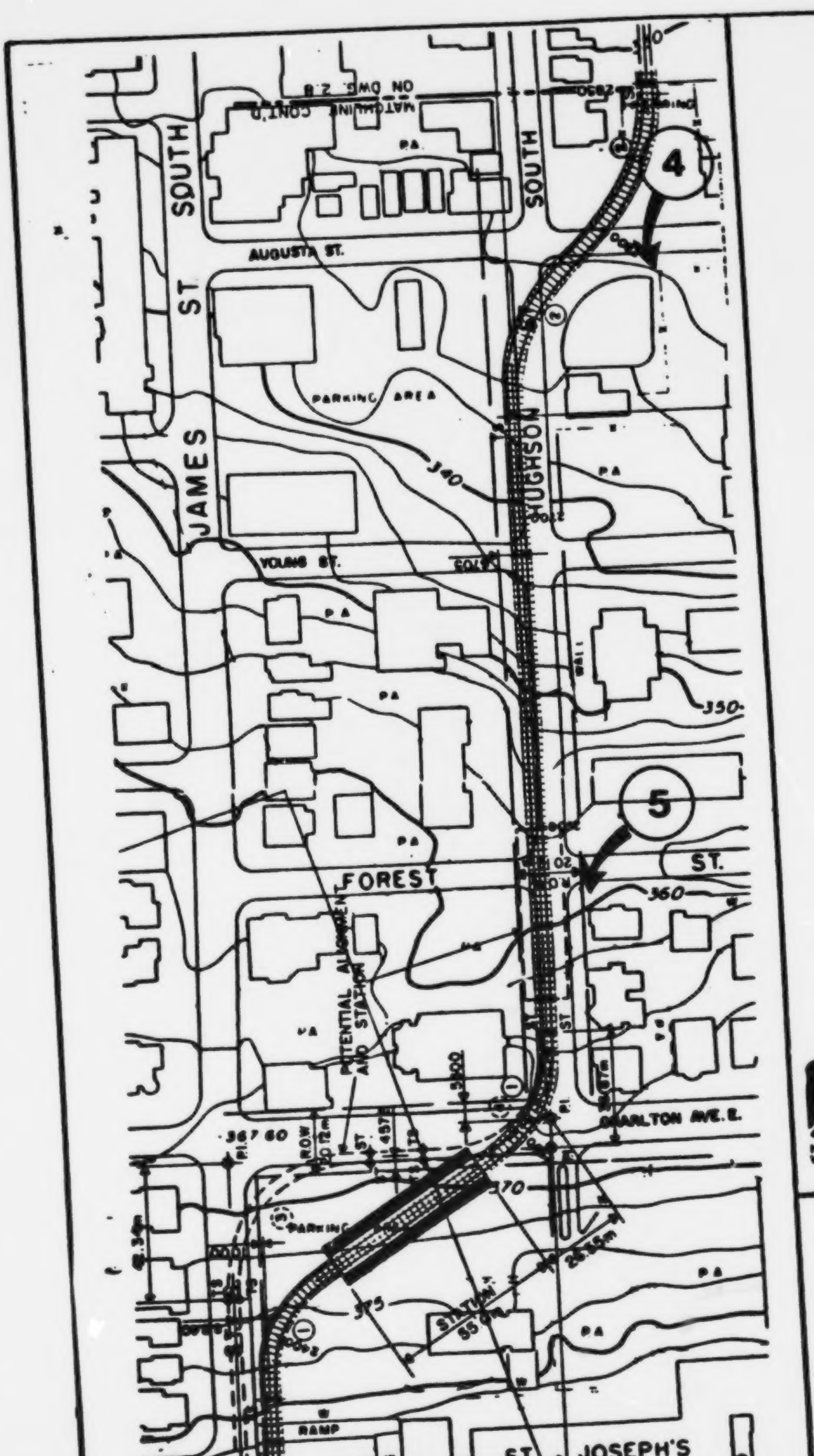

KING WILLIAM ST.
KING ST.
MAIN ST.
JACKSON ST.
HUNTER ST.
JOHN ST
SOUTH
BOWEN ST
CATHARINE ST
SOUTH
OPTIONAL STATION
REVERSED CURVE 77.66m
38.83m
22.00m
2592
2650
R.O.W.
20.12m
MATCHLINE CONT'D ON DWG 2 B
310
350
322.5
321
2
5 4 3 2 1 0 5m 10m
VERT. SCALE 1:250
HAMILTON/WENTWORTH

HAMILTON-WENTWORTH

RAPID TRANSIT PROJECT

FIGURE 3

MEASUREMENT LOCATION 2

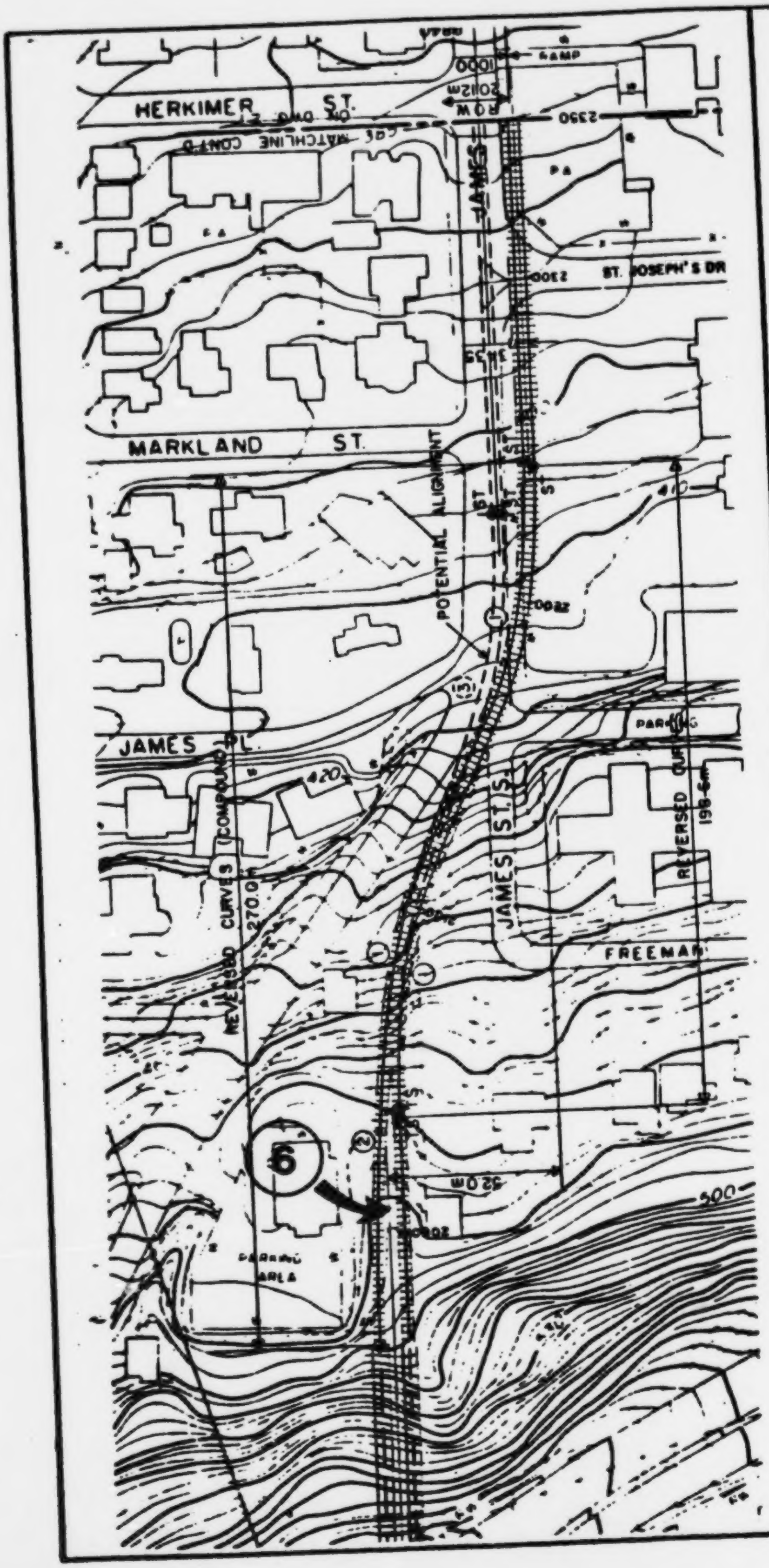

4
5
JAMES ST SOUTH
HUGHSON ST SOUTH
AUGUSTA ST.
YOUNG ST.
FOREST ST.
CHARLTON AVE. E.
ST. JOSEPH'S
PARKING AREA
PARKING
RAMP
P.A
POTENTIAL ALIGNMENT AND STATION
STATION 85.0m
340
350
360
370
375
543210 5m 10m
VERT. SCALE 1:250

HAMILTON-WENTWORTH

RAPID TRANSIT PROJECT

FIGURE 4

MEASUREMENT LOCATIONS 4 AND 5


HERKIMER ST.
MATCHLINE CONT'D ON DWG 2
ROW 20.12m
1000
RAMP
2390
JAMES
ST. JOSEPH'S DR
2300
35.39
MARKLAND ST.
POTENTIAL ALIGNMENT
ST.
JAMES ST.
410
2200
JAMES PL.
PARKING
420
REVERSED CURVES (COMPOUND) 270.0m
REVERSED CURVES 198.6m
JAMES ST. S.
FREEMAN
6
20.12m
2000
500
PARKING AREA

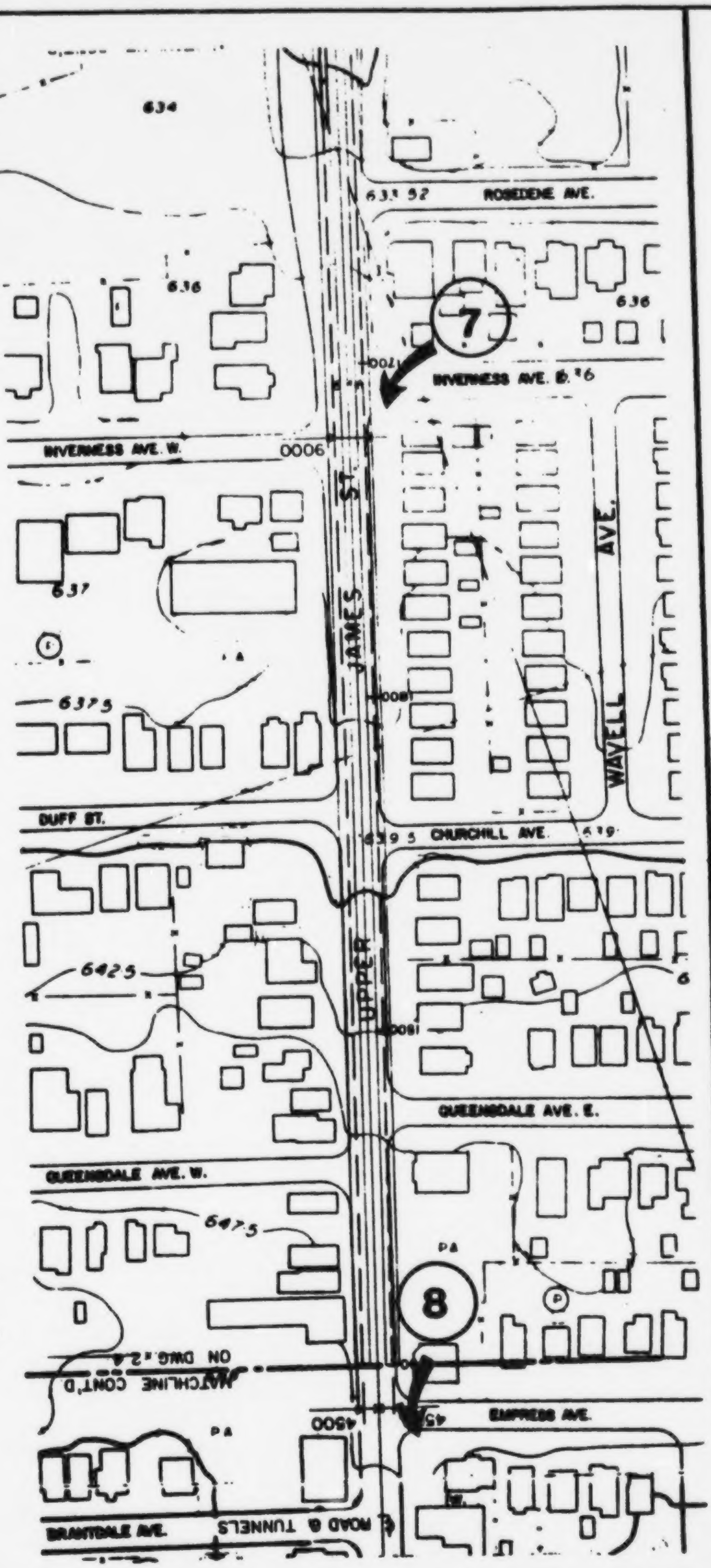
5 4 3 2 1 0 5m 10m

VERT. SCALE 1:250

HAMILTON-WENTWORTH RAPID TRANSIT PROJECT

FIGURE 5

MEASUREMENT LOCATION 6

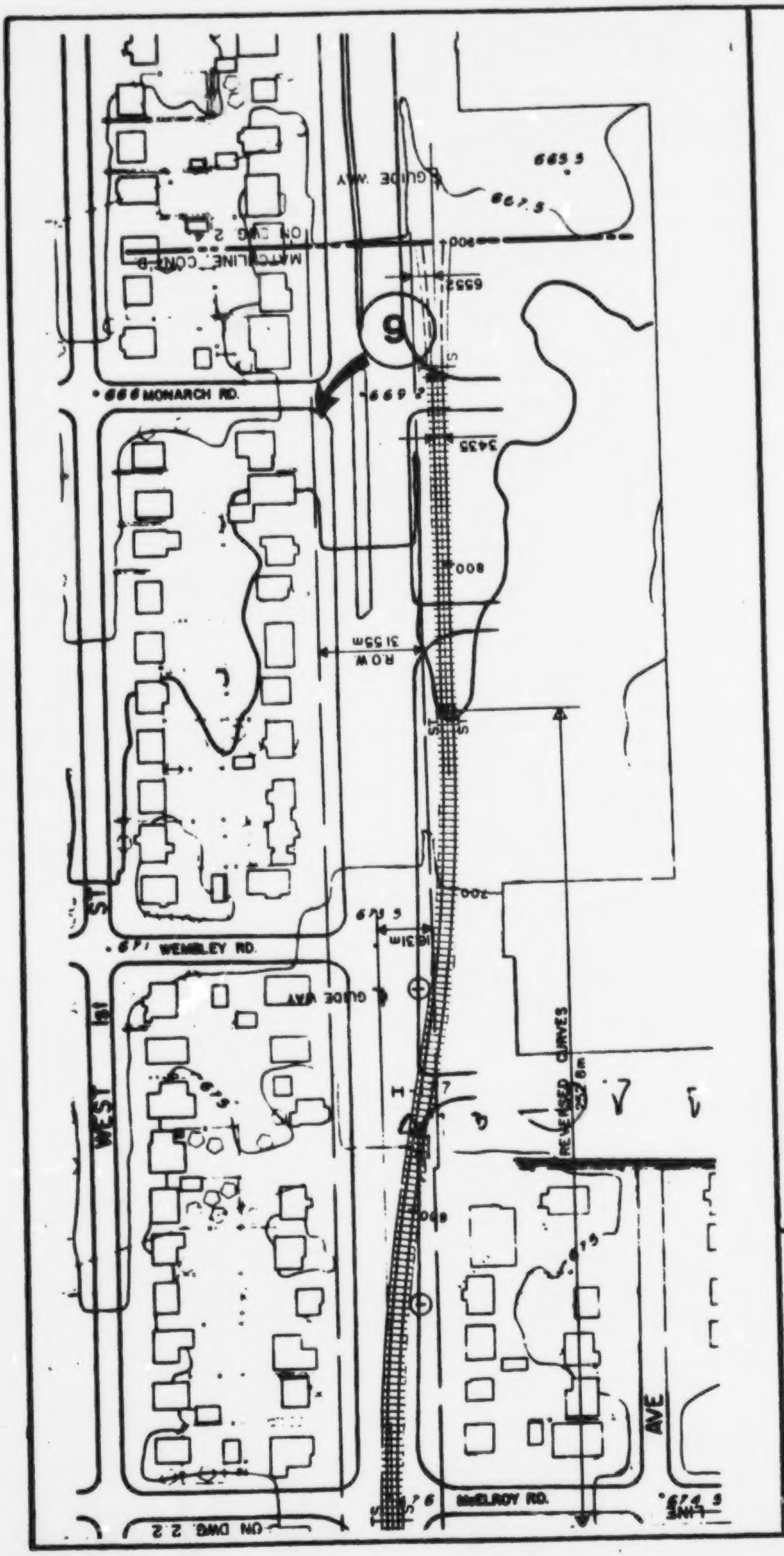

634
633.52
ROSEDENE AVE.
636
636
7
INVERNESS AVE. E.
INVERNESS AVE. W.
0006
637
637.5
UPPER JAMES ST.
WAVELL AVE.
DUFF ST.
639.5
CHURCHILL AVE.
642.5
QUEENSDALE AVE. E.
QUEENSDALE AVE. W.
647.5
8
MATCHLINE CONT'D ON DWG. 2.4
4500
EMPRESS AVE.
BRANTDALE AVE.
ROAD & TUNNELS

543210 5m 10m
VERT. SCALE 1:250

HAMILTON-WENTWORTH
RAPID TRANSIT PROJECT

FIGURE 6

MEASUREMENT LOCATIONS 7 AND 8

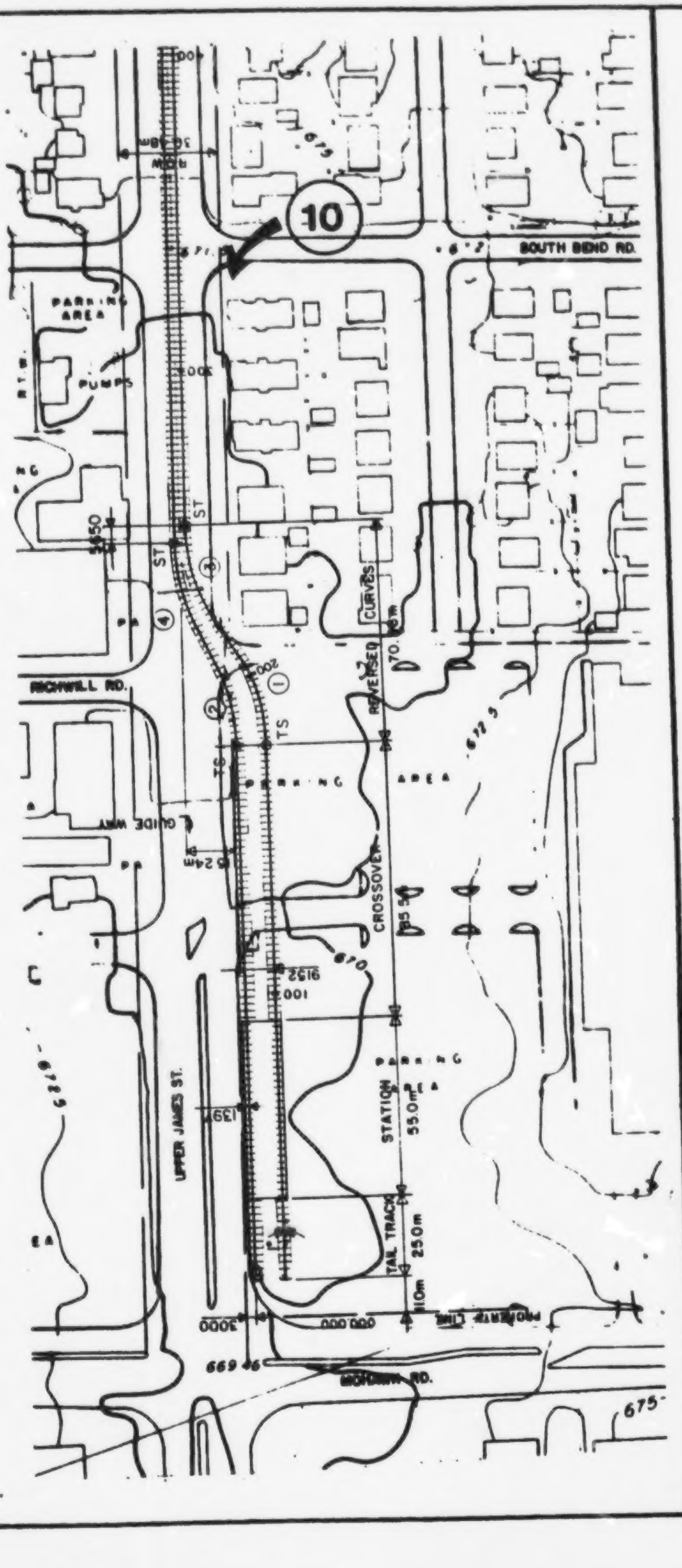

665.5
667.5
GUIDE WAY
MATCHLINE CONT'D ON DWG 2
900
6552
9
669.2
666 MONARCH RD.
3435
800
ROW 31.55m
ST
700
671.5
16.31m
671 WEMBLEY RD.
GUIDE WAY
WEST
ST
REVERSED CURVES 257.8m
675
600
676 McELROY RD.
674.5
LINE
AVE
ON DWG 2.2

5 4 3 2 1 0 5m 10m
VERT. SCALE 1:250

HAMILTON-WENTWORTH
RAPID TRANSIT PROJECT

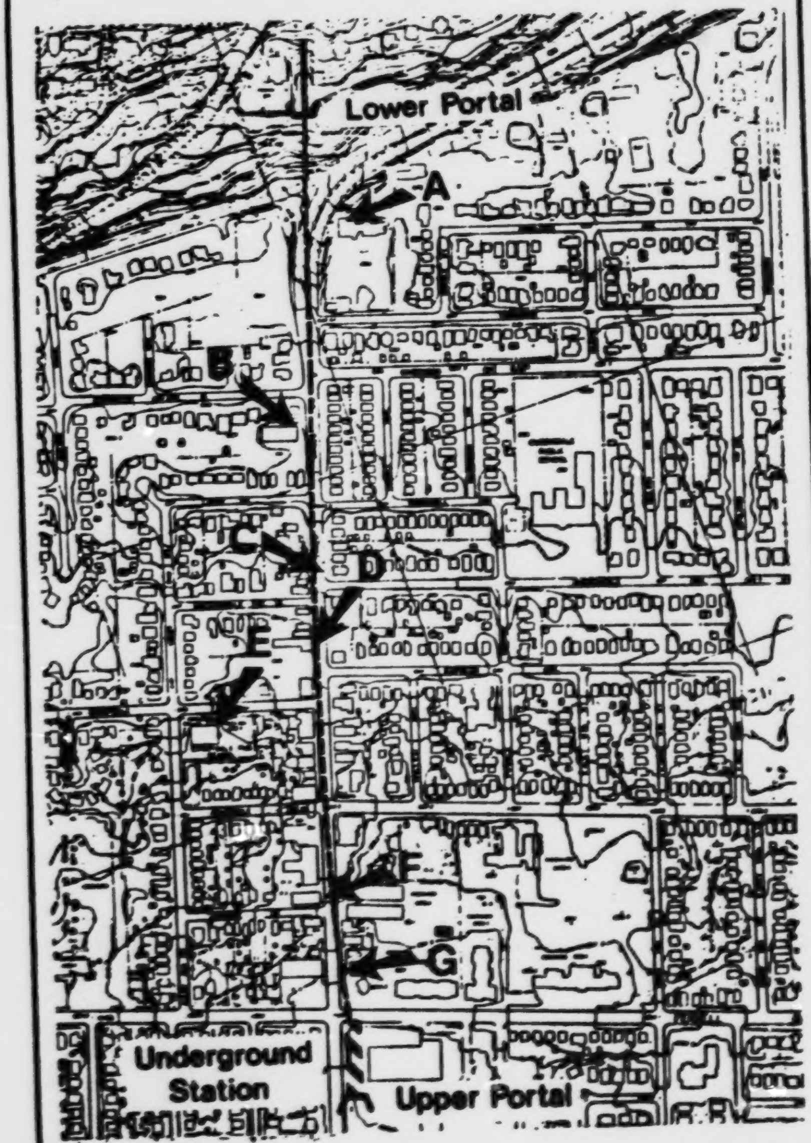
FIGURE 7

MEASUREMENT
LOCATION 9


10
30.48m
ROW
SOUTH BEND RD.
PARKING AREA
PUMPS
ST
TS
① ② ③ ④
RICHWILL RD.
REVERSED CURVES
70.0m
PARKING AREA
GUIDE WAY
CROSSOVER
35.5
670
UPPER JAMES ST.
STATION
55.0m
TAIL TRACK
25.0m
10m
PROPERTY LINE
669.46
MOHAWK RD.
675
672.5
543210 5m 10m
VERT. SCALE 1:250

HAMILTON-WENTWORTH
RAPID TRANSIT PROJECT

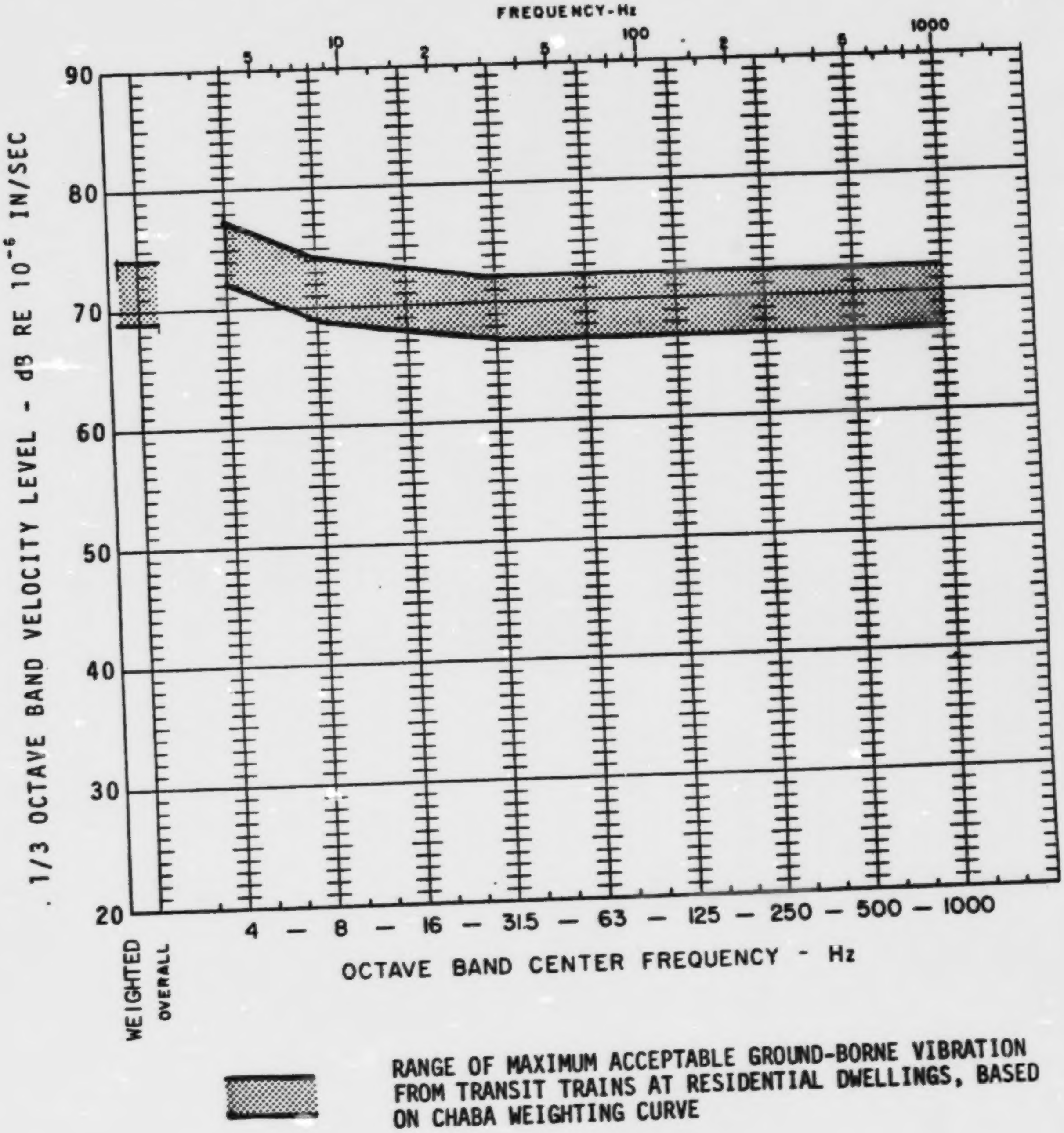
FIGURE 8
MEASUREMENT
LOCATION 10


Lower Portal
A
B
C
D
E
F
G
Underground Station
Upper Portal

HAMILTON-WENTWORTH
RAPID TRANSIT PROJECT

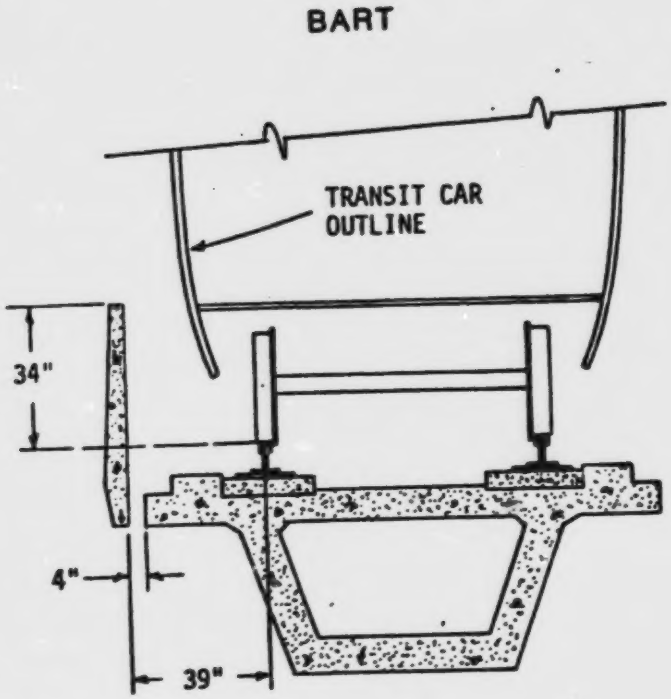
FIGURE 9

APPROXIMATE SITE LOCATIONS FOR NOISE AND VIBRATION PREDICTIONS LISTED IN TABLE IX ON PAGE 35



▨ RANGE OF MAXIMUM ACCEPTABLE GROUND-BORNE VIBRATION FROM TRANSIT TRAINS AT RESIDENTIAL DWELLINGS, BASED ON CHABA WEIGHTING CURVE

FIGURE 10 CRITERIA FOR MAXIMUM GROUND-BORNE VIBRATION LEVELS IN TERMS OF VIBRATION VELOCITY LEVEL


BART
TRANSIT CAR OUTLINE
34"
4"
39"

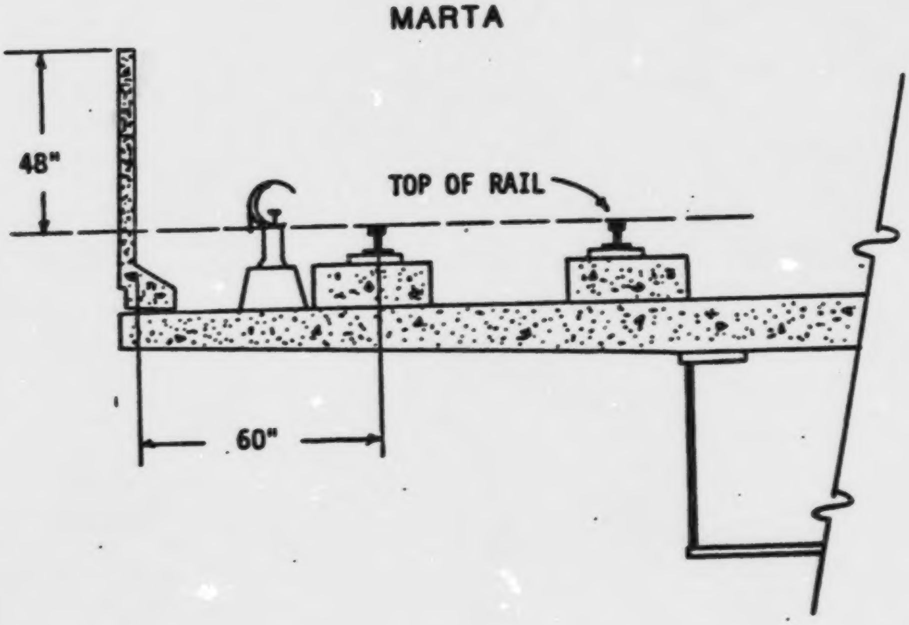

MARTA
48"
TOP OF RAIL
60"

FIGURE 11 SOUND BARRIERS FOR AERIAL STRUCTURES, BART AND MARTA

REFERENCES

1. "City of Hamilton Noise Control By-Law", By-Law No. 79-292, City of Hamilton, Ontario, October 1979.

2. "Guidelines for Preparing Environmental Impact Statements on Noise", CHABA (Committee on Hearing, Bioacoustics and Biomechanics), June 1977.

3. "Model Municipal Noise Control By-Law", Ministry of the Environment, Ontario, August 1978.

4. "Guidelines and Principles for Design of Rapid Transit Facilities", APTA (American Public Transit Association), 1979.

5. Memo: "Steel Guideway Study - Noise/Vibration Baseline Data", from L. Gray and G. Unsworth to H. Ledsham, March 9, 1981.

6. Memo: "ICTS Sound and Vibration Evaluation Kingston Trip, 81 May 22", TTC Research Memo #693, contained in letter from D.J. Morton to G. Unsworth, July 16, 1981.

7. "Hamilton-Wentworth Rapid Transit Study, Ambient Noise Survey, Environmental Assessment Task E-5", Marshall, Macklin, Monaghan/Hatch Associates, April 1981.

GLOSSARY

A-Weighted Decibel (dBA): A measure of sound which weights the various frequencies comprising a sound in a manner which approximates the perceptions of the human ear.

Airborne Sound: Sound radiated initially into and transmitted through air rather than through solids or the structure of a building.

Decibel (dB): A unit used to denote the logarithm of the ratio of two quantities. For sound it is $20\log_{10}$ of the ratio of the sound pressure to a reference pressure of 20 micro Pascals ($20\mu Pa$). For vibration velocity it is $20\log_{10}$ of the ratio of the vibration velocity to a reference velocity of 1 micro inch per second.

Frequency: The number of complete cycles per second of a vibration or other periodic motion. Usually stated in Hertz (Hz) or the obsolete cycles per second (cps).

Hertz: The unit of measure of frequency, equivalent to cycles per second (cps).

Noise: Unwanted sound.

Noise Level (Sound Level): A-weighted sound pressure level.

Sound Pressure Level: A value, expressed in decibels, equal to $20\log_{10}$ of the pressure of sound to the reference pressure of 20 micro Pascals ($20\mu Pa$).

APPENDIX 1

TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT
RESEARCH SECTION

RESEARCH MEMO #693

ICTS SOUND & VIBRATION EVALUATION
KINGSTON TRIP, 81 MAY 22

TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT
RESEARCH SECTION

June 25, 1981

Research Memo #693

ICTS Sound & Vibration Evaluation
Kingston Trip, 81 May 22

Introduction: At the request of Mr. S.T. Lawrence, General Manager - Engineering & Construction, staff from the Engineering Department, Research Section visited the UTDC (Urban Transportation Development Corporation) test facility in Kingston on May 22nd to perform a sound and vibration (S&V) survey of the ICTS (Intermediate Capacity Transit System) vehicle. The survey comprised of S&V measurements done adjacent to at grade track and elevated structure track. The ICTS vehicle (TV2 solid steel wheels) operated on a concrete track slab. The track fastener system is a Pandrol-type direct fixation on at grade structure and Hixson fastener on the elevated structure.

The data from the survey was for use in the evaluation of the ICTS for possible use on the SLRT (Scarborough Light Rail Transit) line.

Test Details:

Date - 81 May 22

Location - Kingston UTDC test facility for ICTS. See Figure 1 for sketch of a test facility and Figures 4A & 4B for photographs.

Staff - Messrs. A.D. Hunt, J.K. Powell) TTC Engineering Dept.
M.C. Carrington, D.R. Hurst) Research Section

- Several UTDC employees.

Equipment:

Measurement - See Figures 1, 2 and 3 - To simplify and speed up the measurement survey, use was made of additional Nagra IV-SJ tape recorder made available by Mr. G. Unsworth (Metro Canada - Kingston). The vibration data was recorded on this instrument. The sound data was recorded on the Research Nagra IV-SJ tape recorder. Vehicle speeds were measured using a Tribar hand-held radar unit and confirmed by an on-car speed indicator.

Analysis - See Figure 3. All data was analyzed using the Research tape recorder including the vibration data recorded on Mr. Unsworth's recorder. This was possible since the vibration data was recorded in FM which does not require a known or uniform tape recorder frequency response.

Results: Figure 5 is a table of the overall sound and vibration levels recorded at the at grade and elevated structure measurement locations.

Figures 6-11 are frequency analysis graphs for sound data recorded at grade. Figures 6-10 are of data recorded at 20 m and 40 m at the three test speeds of 40 km/h (25 MPH), 56 km/h (35 MPH) and 72 km/h (45 MPH). Figure 11 is an analysis of the background sound level at 20 m and 40 m.

Figures 12-17 are graphs for vibration data recorded at grade. Figures 12-16 show comparisons at 8 m and 15 m for the three test speeds. Figure 17 is the analysis of the background vibration level at 8 m and 15 m.

Figures 18-23 are graphs of sound data recorded adjacent to the elevated structure. Figures 18-22 are of data recorded at 15 m and 30 m at the three test speeds. Figure 23 is analysis of the background sound level at 15 m and 30 m.

Figures 24-29 are graphs for vibration data recorded adjacent to the elevated structure. Figures 24-28 is analysis data for 8 m and 8.5 m at the three test speeds. Figure 29 is analysis of the background vibration level at 8 m and 8.5 m.

Comments/Discussion:

At Grade

- The analysis of ICTS vehicle passby sound shows there is predominant peak at a frequency of 1000 Hz, subjectively this appears to be the sound from the contact rail/vehicle pickup or from the wheel/rail interface.
- The vibration analysis of passbys gave a 40 Hz peak at all speeds and distances, some secondary peaks occur at 125 and 160 Hz.

Elevated

- Sound analysis showed no distinctive peak frequencies.
- Vibration analysis of passbys gave results showing peak frequencies at 50 and 100 Hz. The overall vibration levels are of very low magnitude. There was a significant increase (6-8 dB) in overall level with an increase in speed from 40 km/h to 56 km/h (25 MPH to 35 MPH).

At Grade vs. Elevated

- The 1000 Hz predominating frequency of sound from ICTS vehicle passbys at grade did not appear in the analysis of elevated structure data. Also, the overall sound levels from the vehicle on the elevated structure were 20 dB lower than at grade. The use of parapet walls on the elevated structure most likely accounts for the loss of the 1000 Hz and 20 dB difference.
- At the 8 m locations, the overall vibration levels measured adjacent to the elevated structure were very low in magnitude relative to those measured at grade. Some of the difference in levels may result from the variables in the characteristics of the vibration transmission path (between wheel/rail contact point and accelerometer) such as the distance being greater for the elevated structure and the structure/soil being different.

Staff Subjective Opinion

- The Research Section staff's subjective opinion of the ICTS vehicle (TV2-solid steel wheels) operating at the Kingston facility on the test date is that it is a quiet and vibrationally unnoticeable transportation vehicle. The sound and vibration analysis data presented in this memo verifies this subjective opinion, particularly the vibration data.

for N. Carrington
J.K. Powell
Eng. Technician

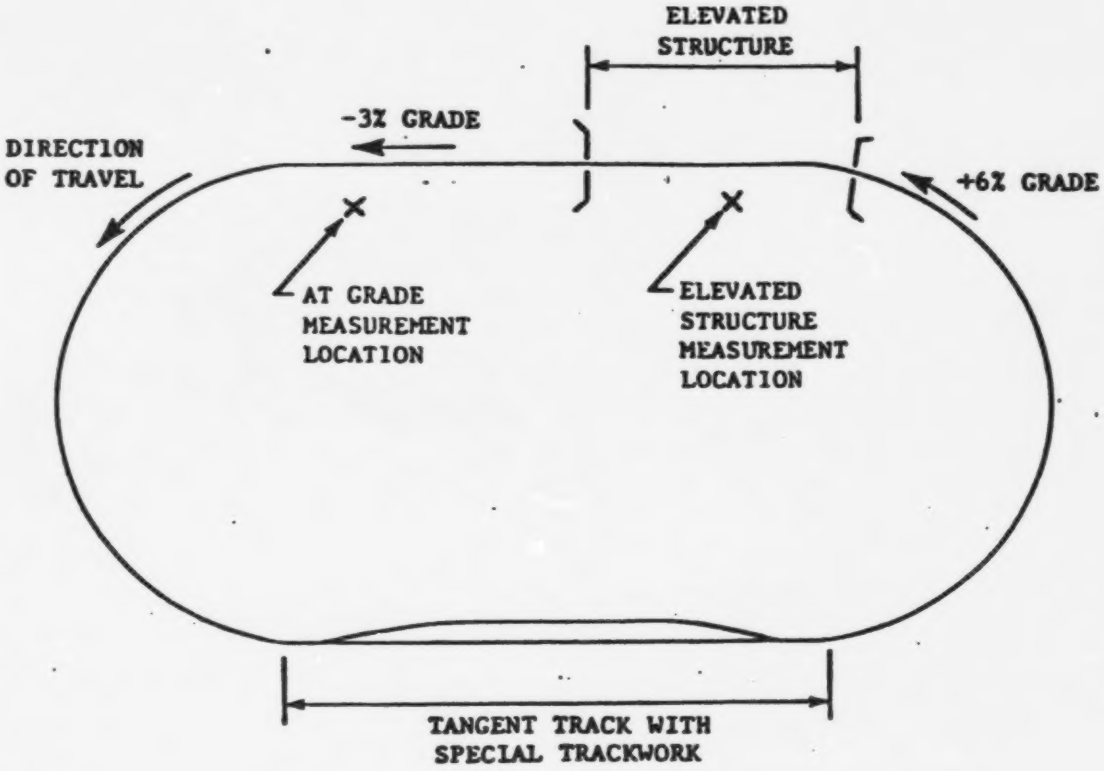
16-112-73
June 25, 1981

F IM SC – 274
Rev. 8/77

TORONTO TRANSIT COMMISSION

ENGINEERING DEPARTMENT

DATA SHEET


ELEVATED STRUCTURE
-3% GRADE
DIRECTION OF TRAVEL
+6% GRADE
AT GRADE MEASUREMENT LOCATION
ELEVATED STRUCTURE MEASUREMENT LOCATION
TANGENT TRACK WITH SPECIAL TRACKWORK

GNATURE JKP

DATE	TITLE	RESEARCH MEMO	FIG NO
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION KINGSTON TEST FACILITY/MEASUREMENT LOCATIONS	693	1

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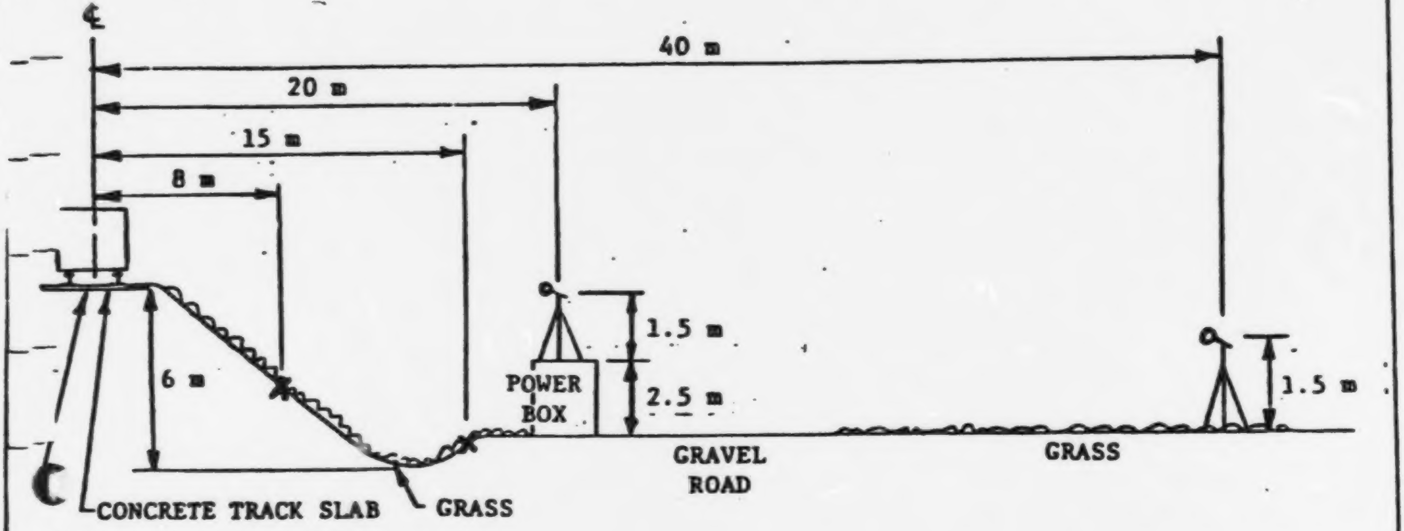
ENGINEERING DEPARTMENT

DATA SHEET

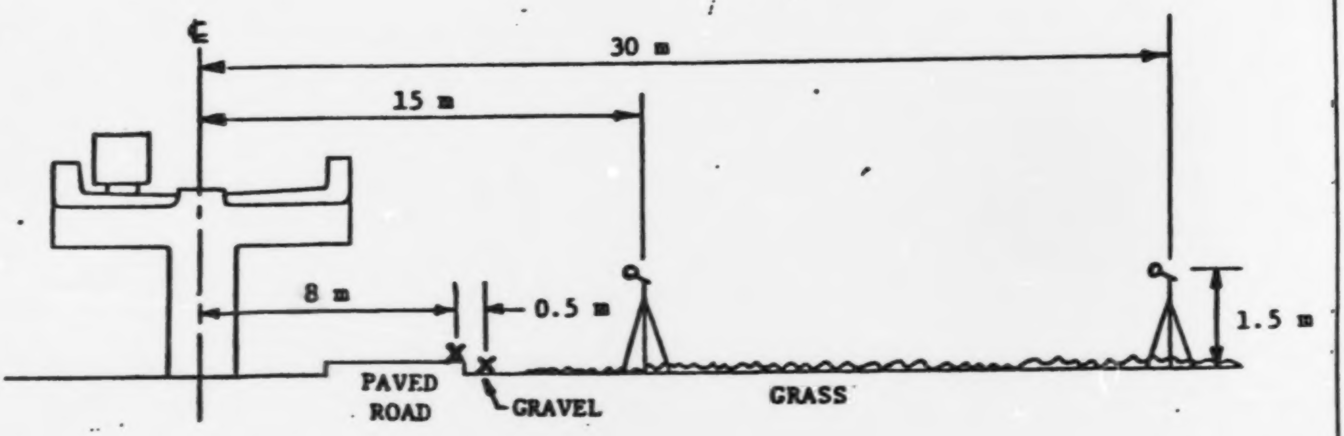
SECTIONS OF TEST SITES

AT GRADE


℄
40 m
20 m
15 m
8 m
1.5 m
6 m
POWER BOX
2.5 m
1.5 m
CONCRETE TRACK SLAB
GRASS
GRAVEL ROAD
GRASS

- TRACK AT 3% DOWNGRADE

ELEVATED STRUCTURE — measurements made at column


℄
30 m
15 m
8 m
0.5 m
1.5 m
PAVED ROAD
GRAVEL
GRASS

LEGEND

× — ACCELEROMETER LOCATION

— MICROPHONE LOCATION

SIGNATURE P.T.N./JKP

DATE		RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION KINGSTON TEST FACILITY/MEASUREMENT LOCATIONS	693	2

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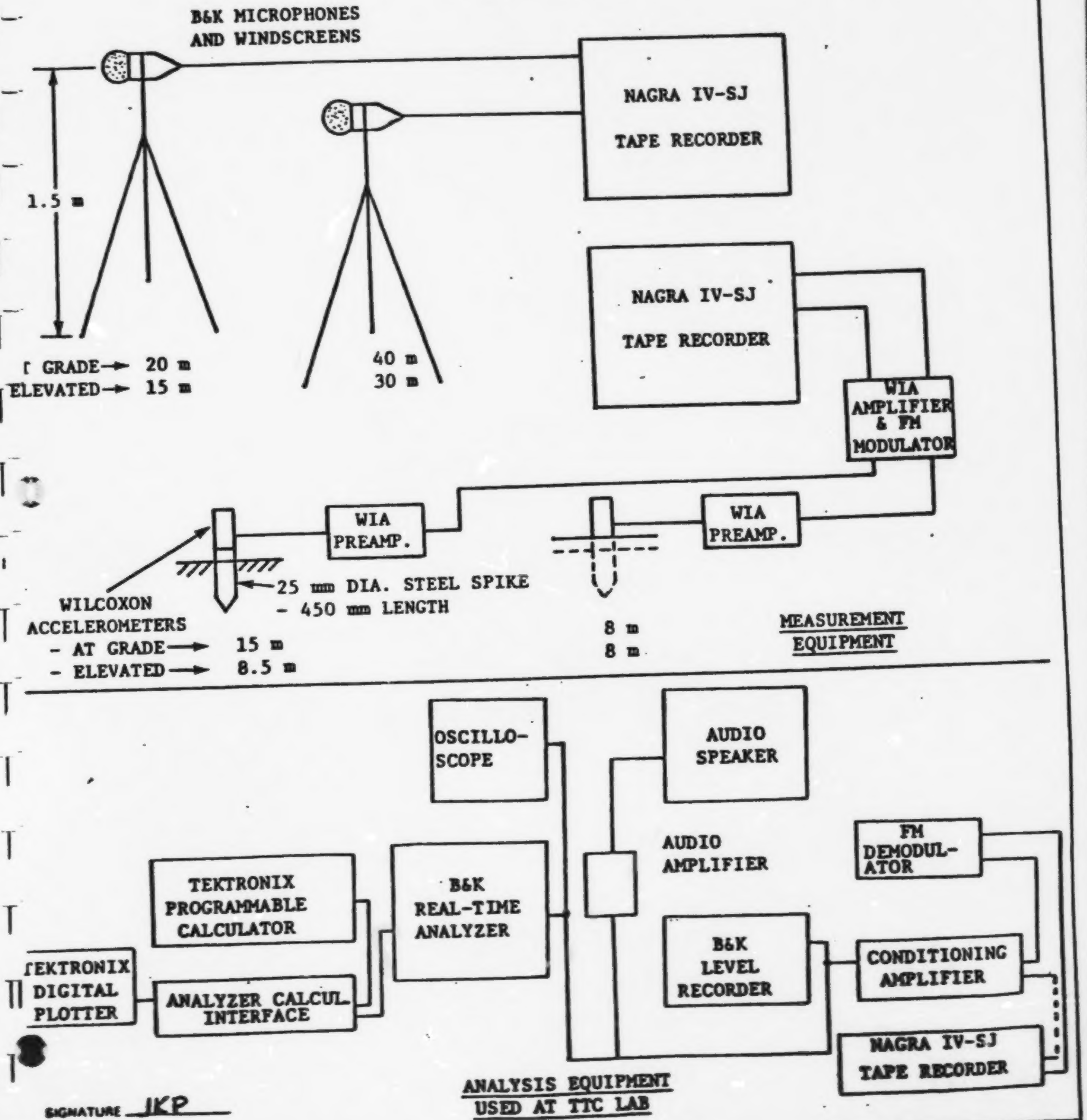
TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT

DATA SHEET


B&K MICROPHONES
AND WINDSCREENS
1.5 m
GRADE → 20 m
ELEVATED → 15 m
40 m
30 m
NAGRA IV-SJ
TAPE RECORDER
NAGRA IV-SJ
TAPE RECORDER
WIA
AMPLIFIER
& FM
MODULATOR
WIA
PREAMP.
WIA
PREAMP.
25 mm DIA. STEEL SPIKE
- 450 mm LENGTH
WILCOXON
ACCELEROMETERS
- AT GRADE → 15 m
- ELEVATED → 8.5 m
8 m
8 m
MEASUREMENT
EQUIPMENT
OSCILLO-
SCOPE
AUDIO
SPEAKER
AUDIO
AMPLIFIER
FM
DEMODUL-
ATOR
TEKTRONIX
PROGRAMMABLE
CALCULATOR
B&K
REAL-TIME
ANALYZER
TEKTRONIX
DIGITAL
PLOTTER
ANALYZER CALCUL.
INTERFACE
B&K
LEVEL
RECORDER
CONDITIONING
AMPLIFIER
NAGRA IV-SJ
TAPE RECORDER
ANALYSIS EQUIPMENT
USED AT TTC LAB

SIGNATURE JKP

DATE		RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	3

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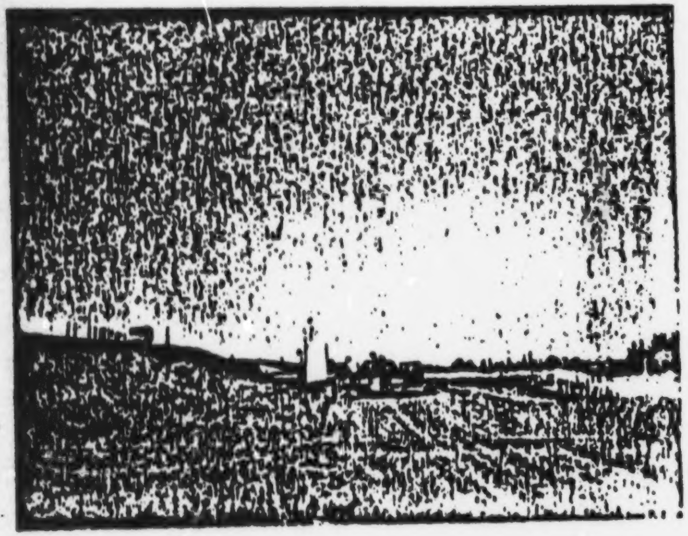
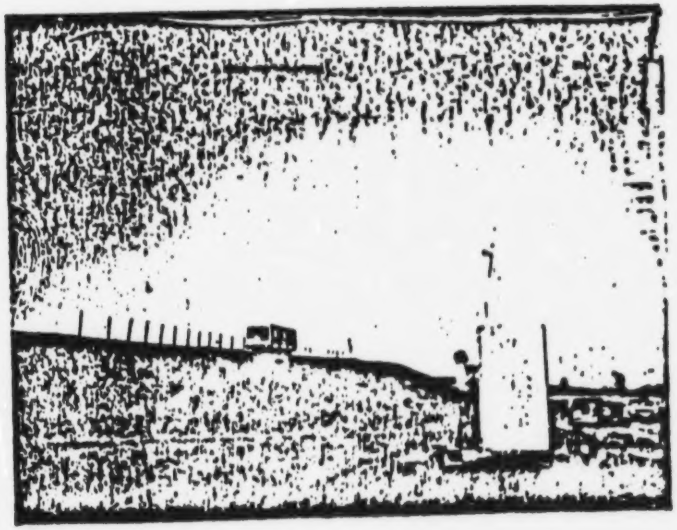
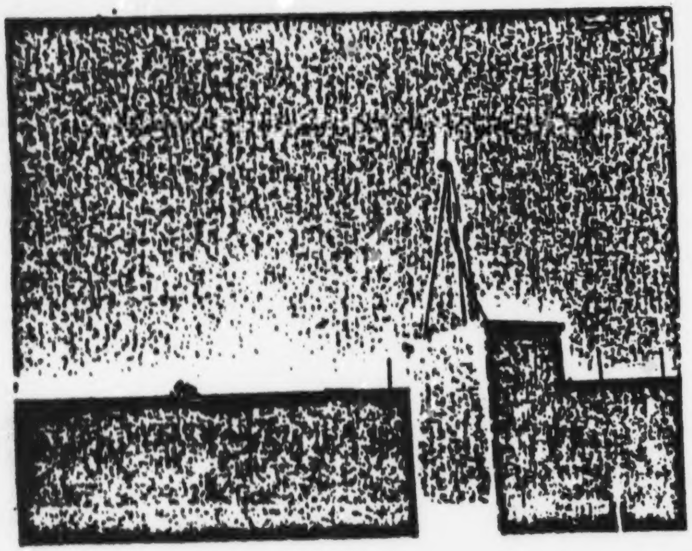
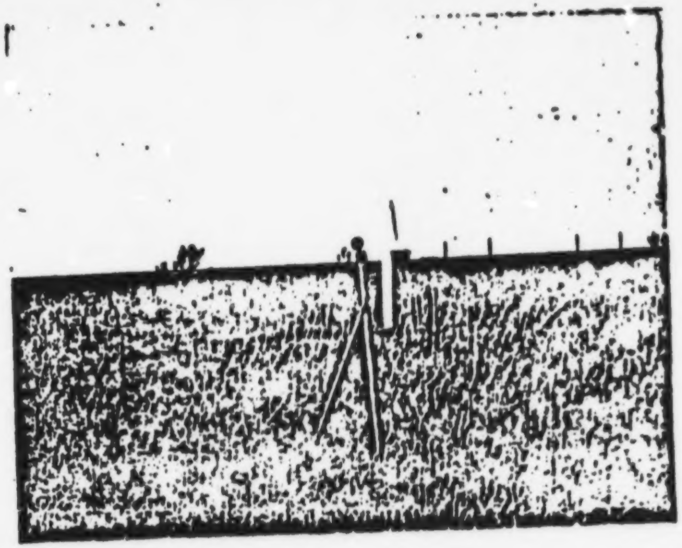
ENGINEERING DEPARTMENT

DATA SHEET









DATE	TITLE	RESEARCH MEMO	FIG NO
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION - PHOTOGRAPHS OF AT GRADE MEASUREMENT LOCATION	693	4A

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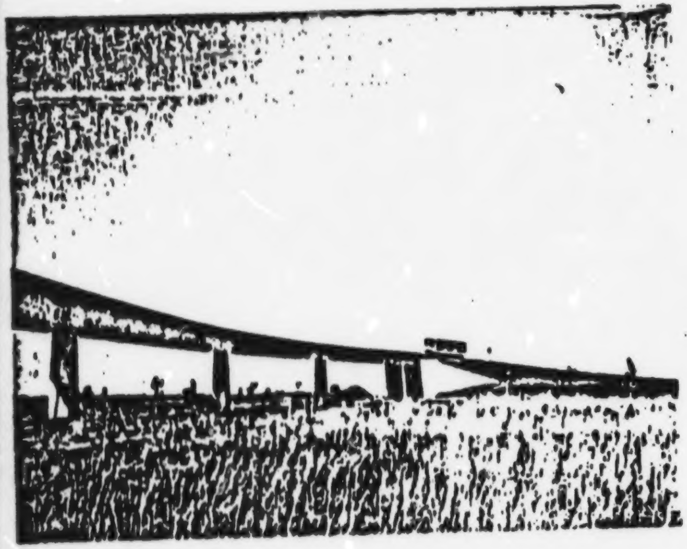
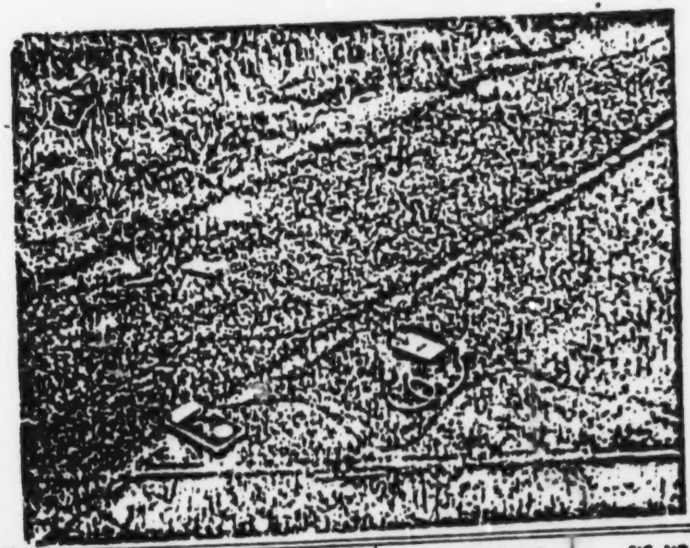
ENGINEERING DEPARTMENT

DATA SHEET





SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG NO
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION - PHOTOGRAPHS OF ELEVATED STRUCTURE MEASUREMENT LOCATION	693	4B

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TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT

DATA SHEET

OVERALL SOUND & VIBRATION LEVELS

AT GRADE MEASUREMENT LOCATION

		SOUND (dBA)		VIBRATION (dB re 10^{-6}g)	
		20m	40m	8m	15m
VEHICLE SPEED	25 MPH (40 km/h)	67	63	55	34
	35 MPH (56 km/h)	68	65	57	37
	45 MPH (72 km/h)	70	66	60	39
BACKGROUND		43	40	26	27

ELEVATED STRUCTURE MEASUREMENT LOCATION

		SOUND (dBA)		VIBRATION (dB re 10^{-6}g)	
		15m	30m	8m	8.5m
VEHICLE SPEED	25 MPH (40 km/h)	46	44	34	35
	35 MPH (56 km/h)	48	48	42	41
	45 MPH (72 km/h)	52	51	43	43
BACKGROUND		34	38	30	28

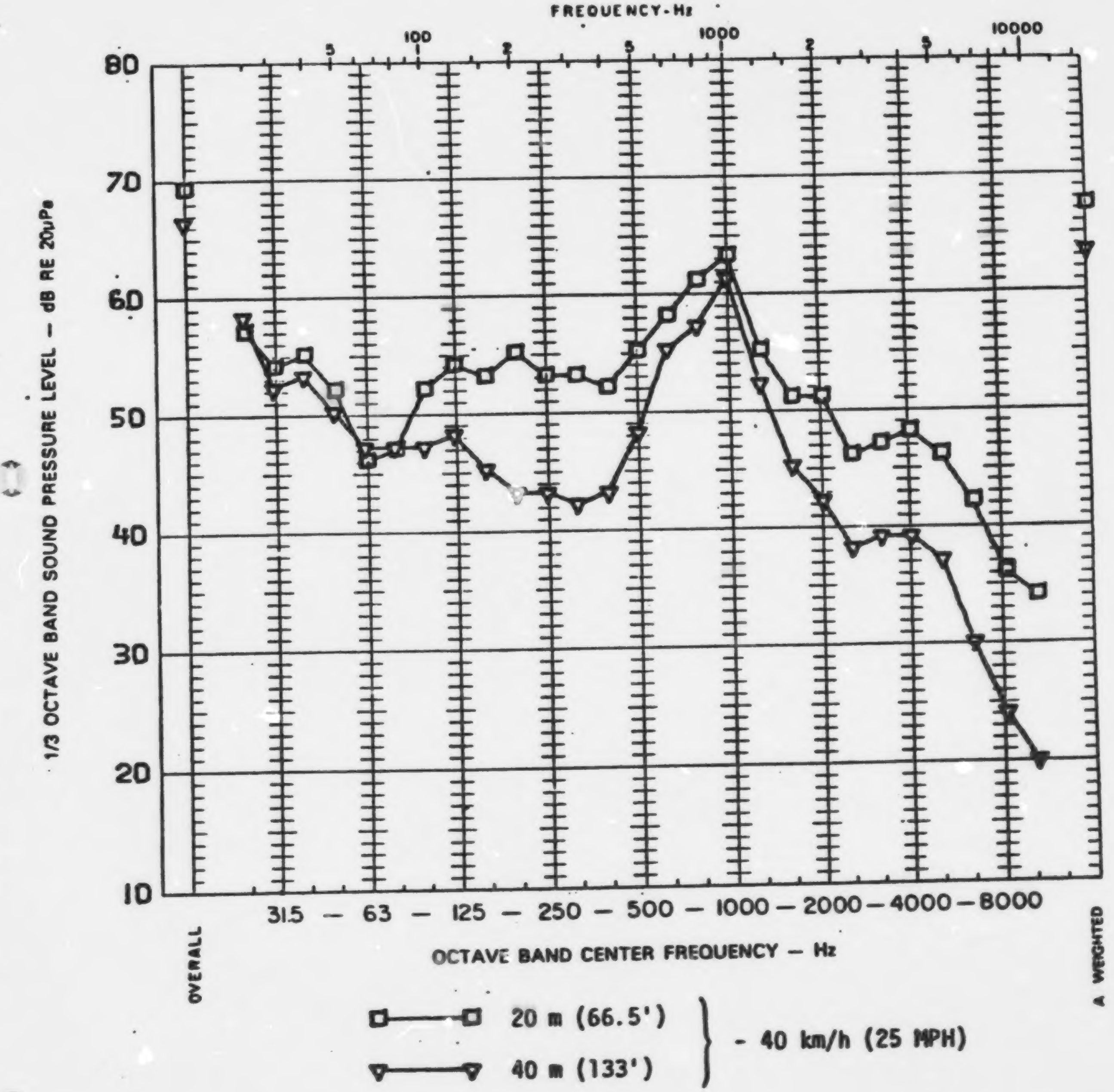
SIGNATURE JKP

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	5

FORM SC-222
REV. 8/77

TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT

SOUND DATA SHEET



SOUND

- ICTS VEHICLE OPERATING AT GRADE

SIGNATURE ____________________

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	6

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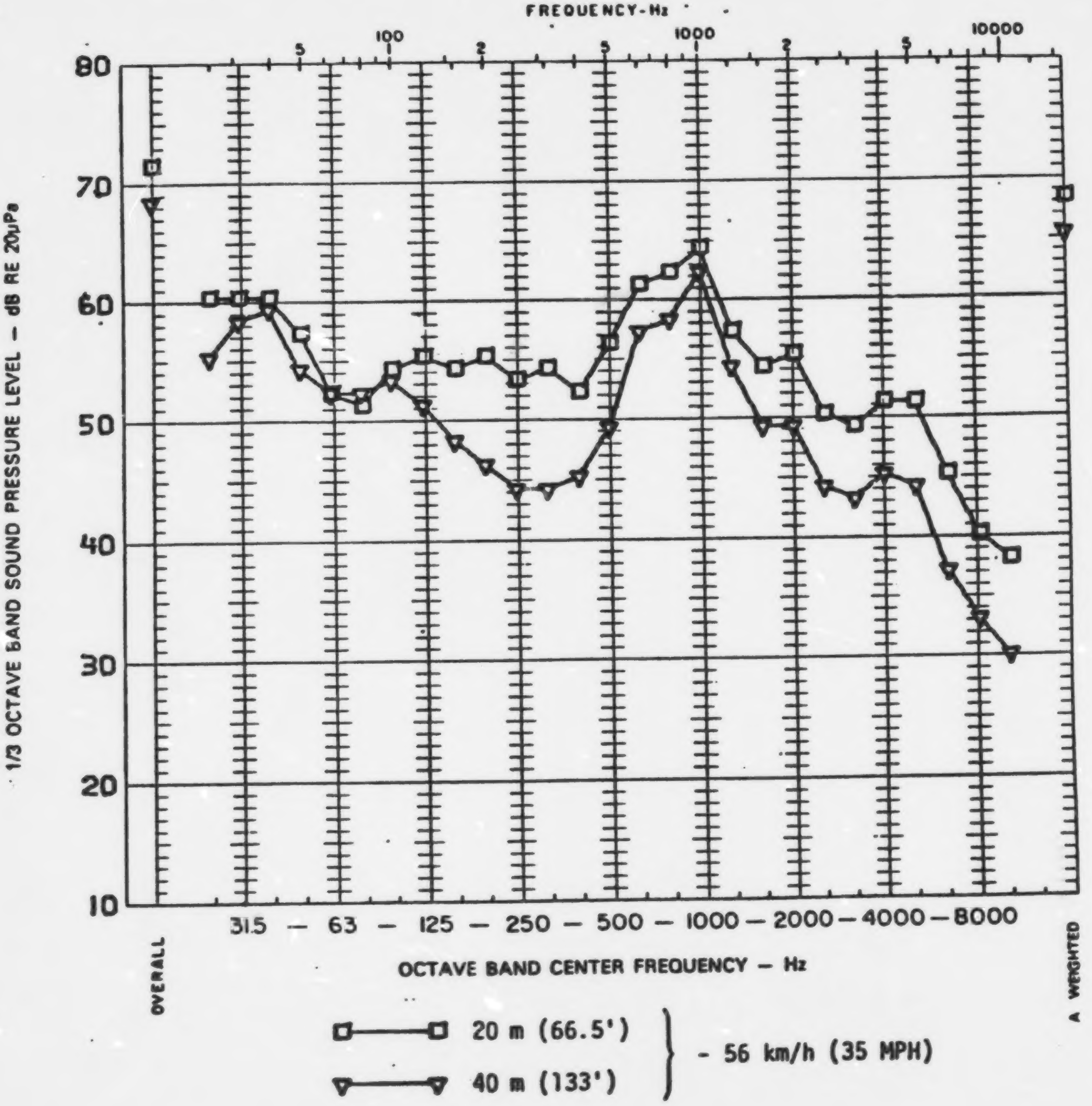
ENGINEERING DEPARTMENT

SOUND DATA SHEET



SOUND

– ICTS VEHICLE OPERATING AT GRADE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	7

FORM SC-222
REV 8/77

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ENGINEERING DEPARTMENT

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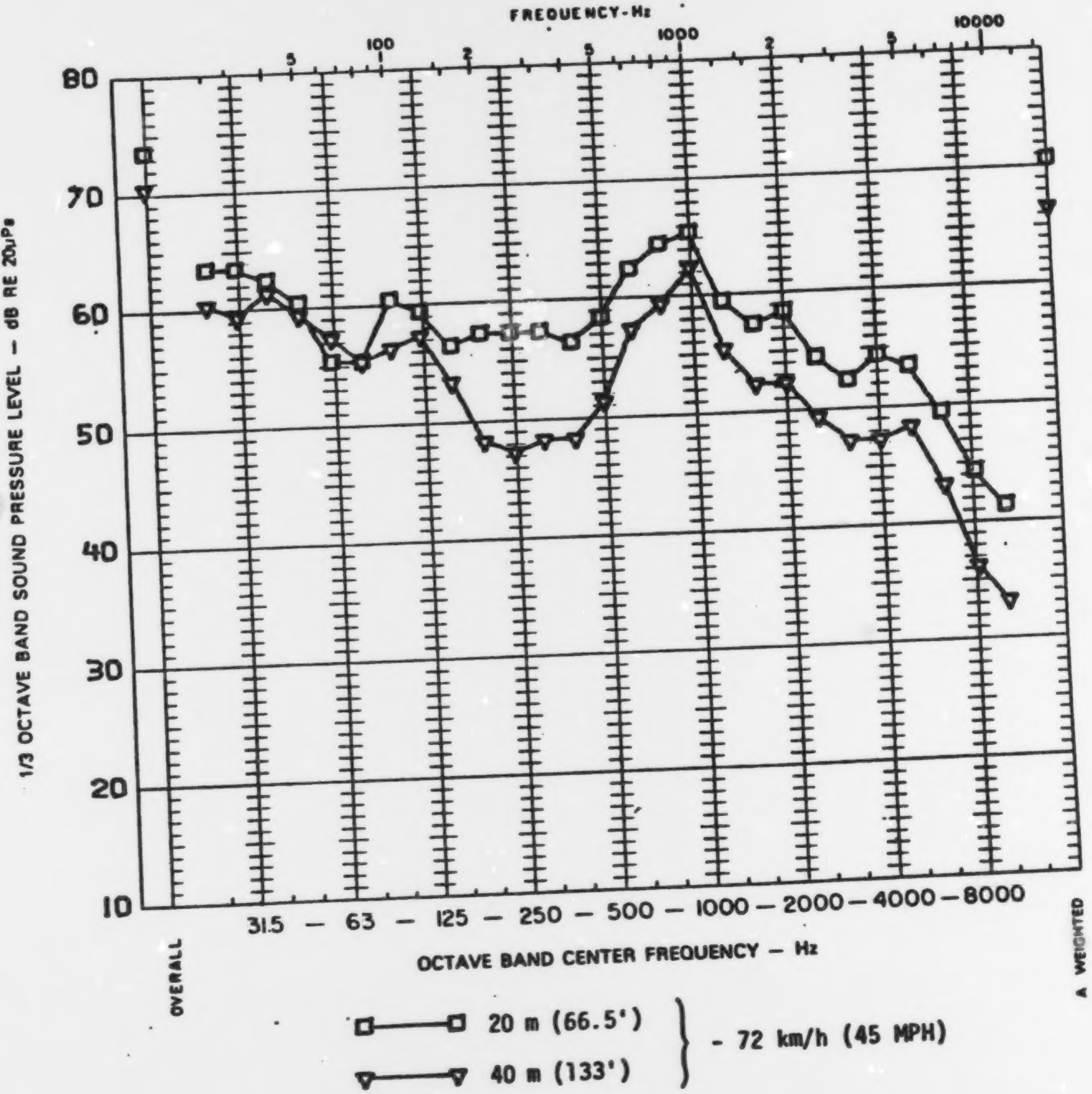

SOUND

- ICTS VEHICLE OPERATING AT GRADE

SIGNATURE ______

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	8

FORM SC-222
REV 9/77

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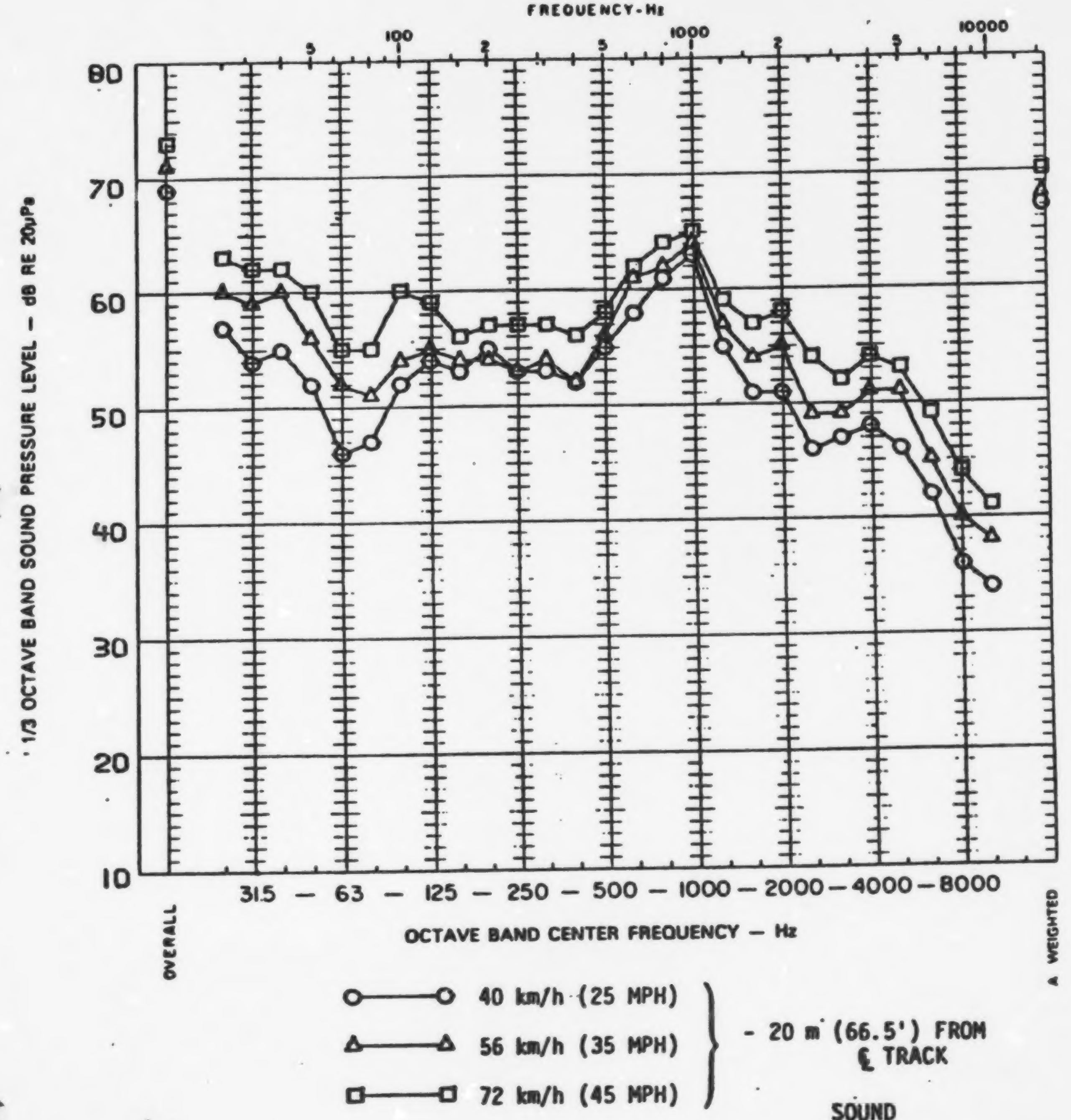
SOUND DATA SHEET



SOUND

- ICTS VEHICLE OPERATING AT GRADE

SIGNATURE ______________

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	9

FORM SC-221
REV. 8/77

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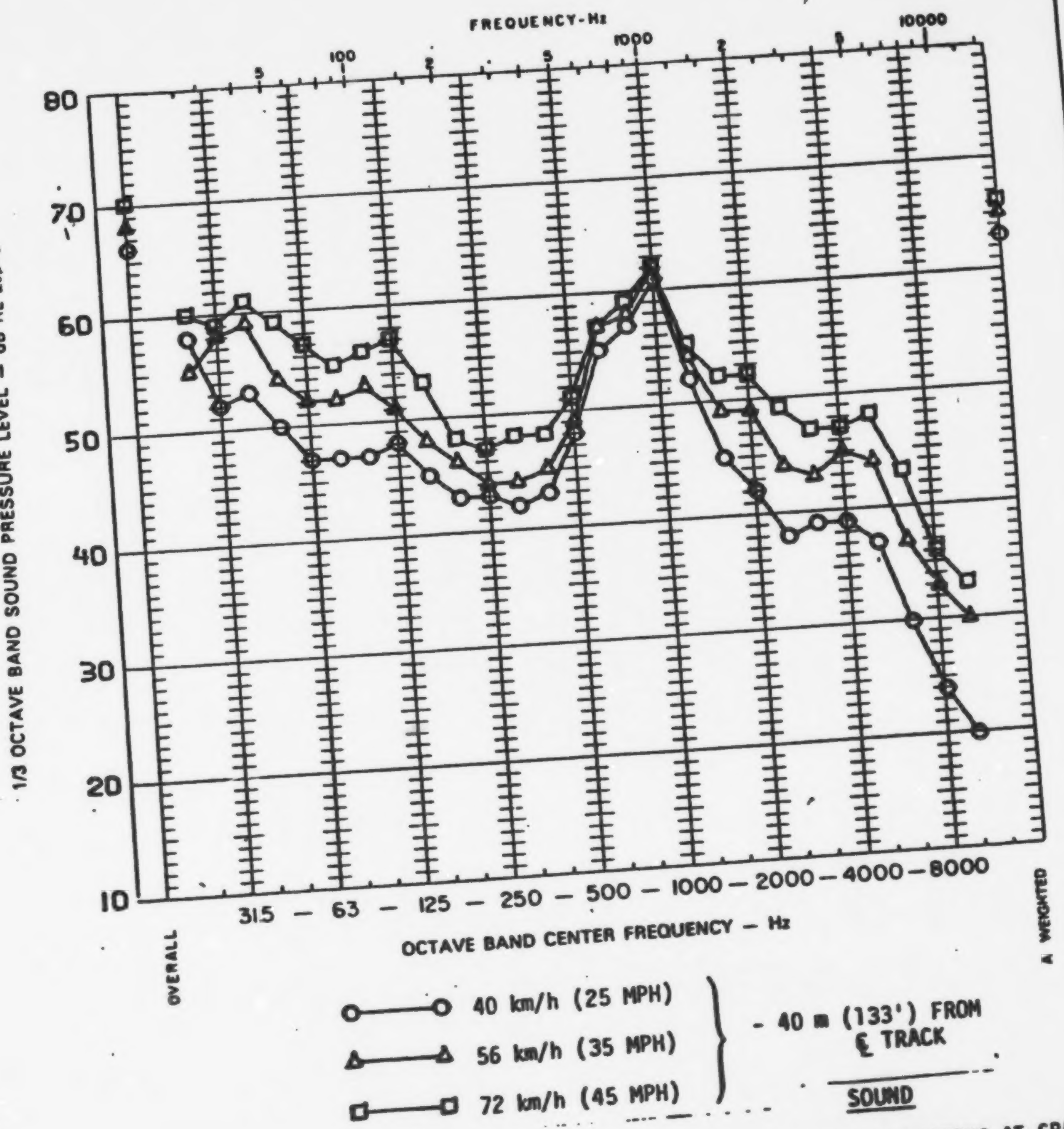

- 40 m (133') FROM ℄ TRACK

SOUND

- ICTS VEHICLE OPERATING AT GRADE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	10

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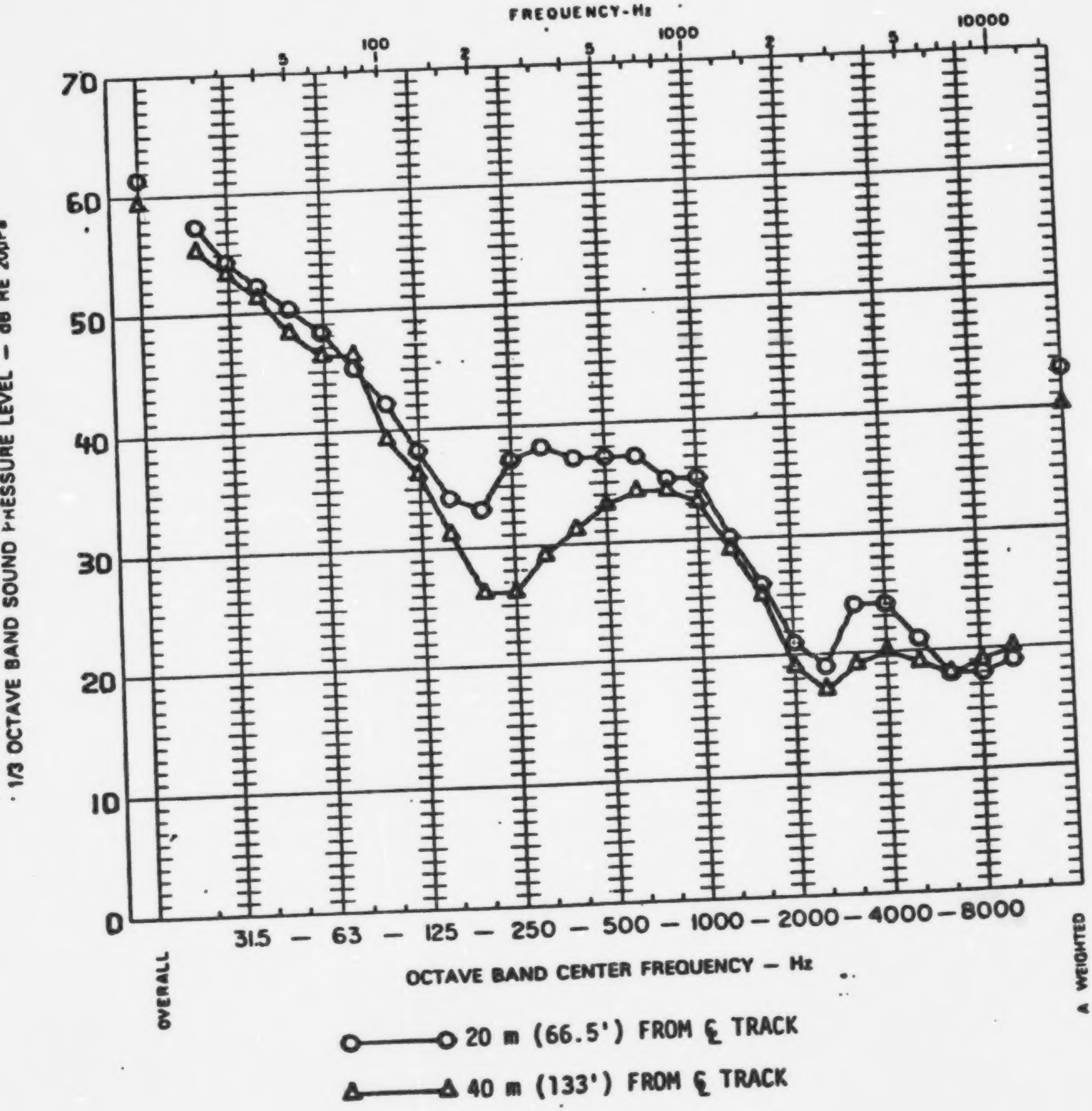

BACKGROUND SOUND

- AT GRADE MEASUREMENT LOCATION

SIGNATURE ____________

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	11

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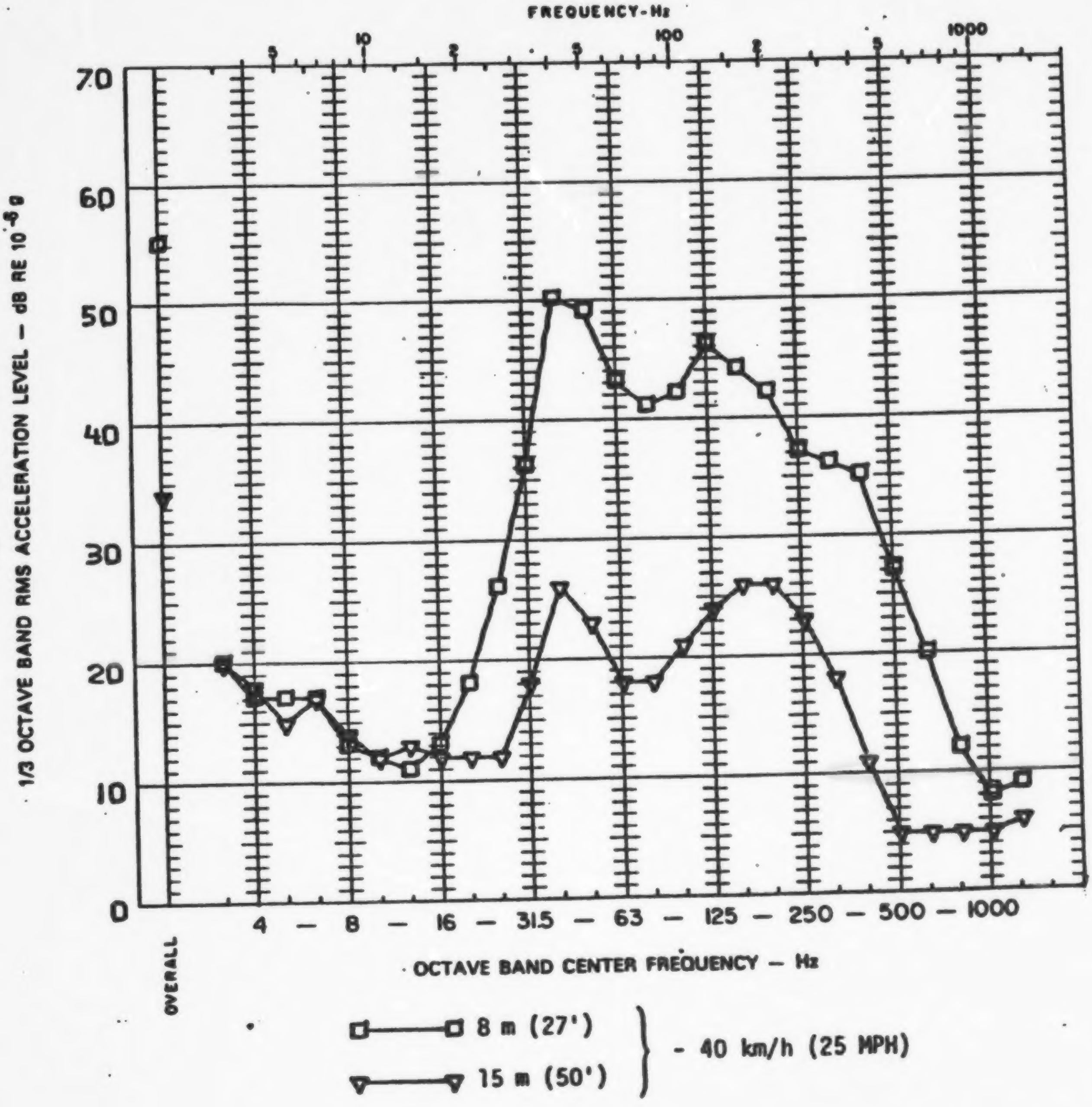

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING AT GRADE

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DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	12

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REV. 8/77

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ENGINEERING DEPARTMENT

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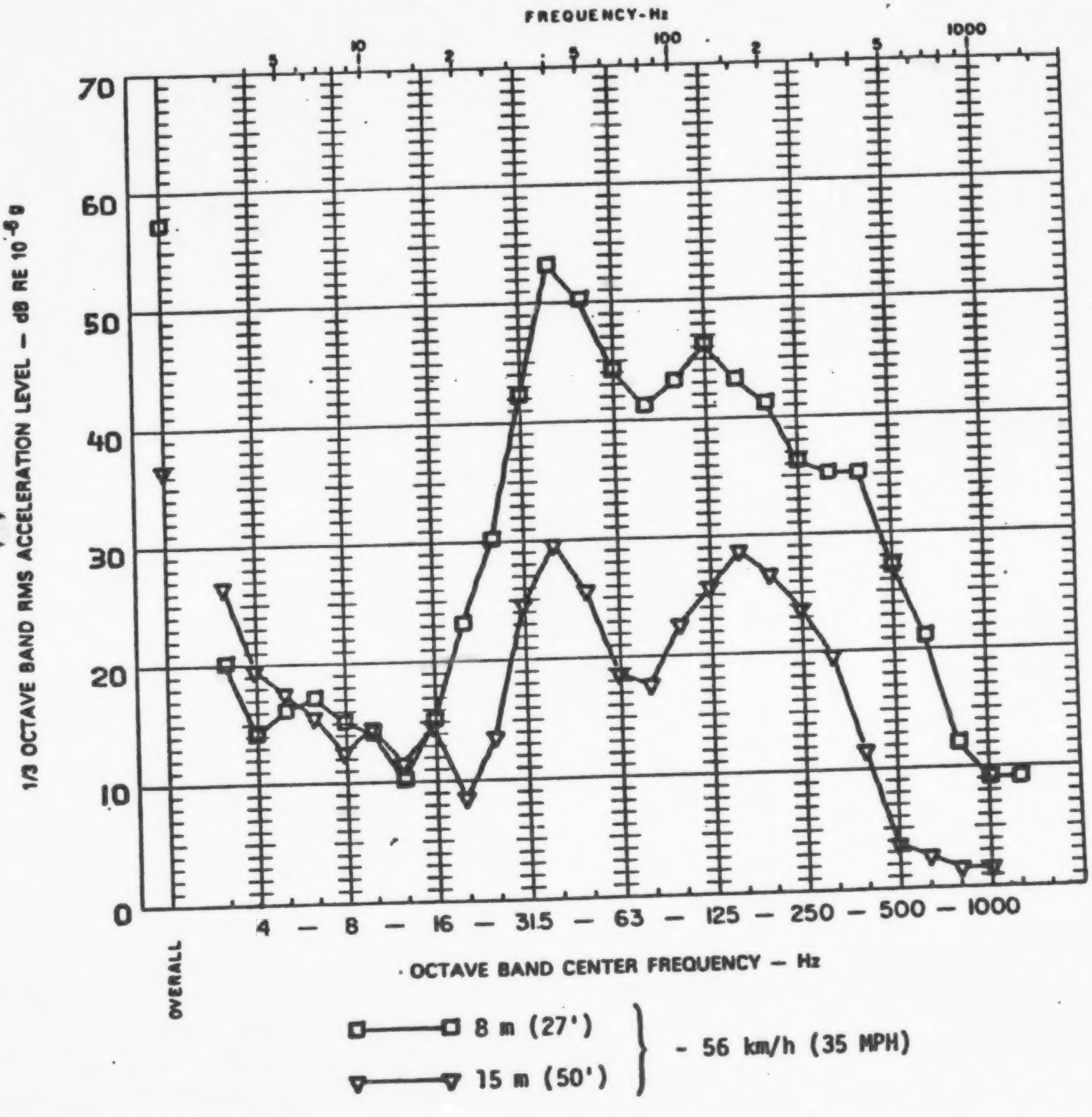

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING AT GRADE

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DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	13

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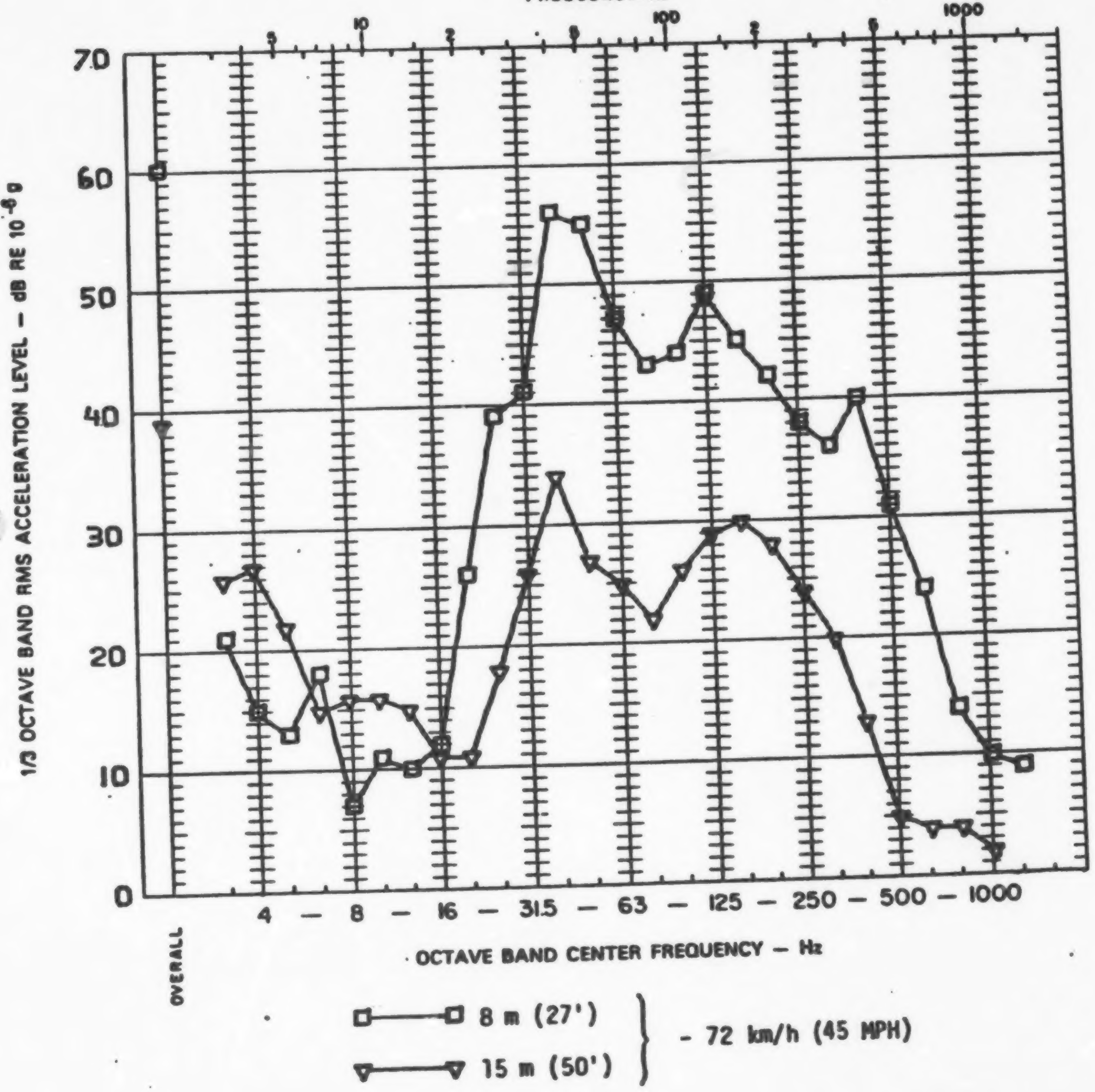

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING AT GRADE

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DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	14

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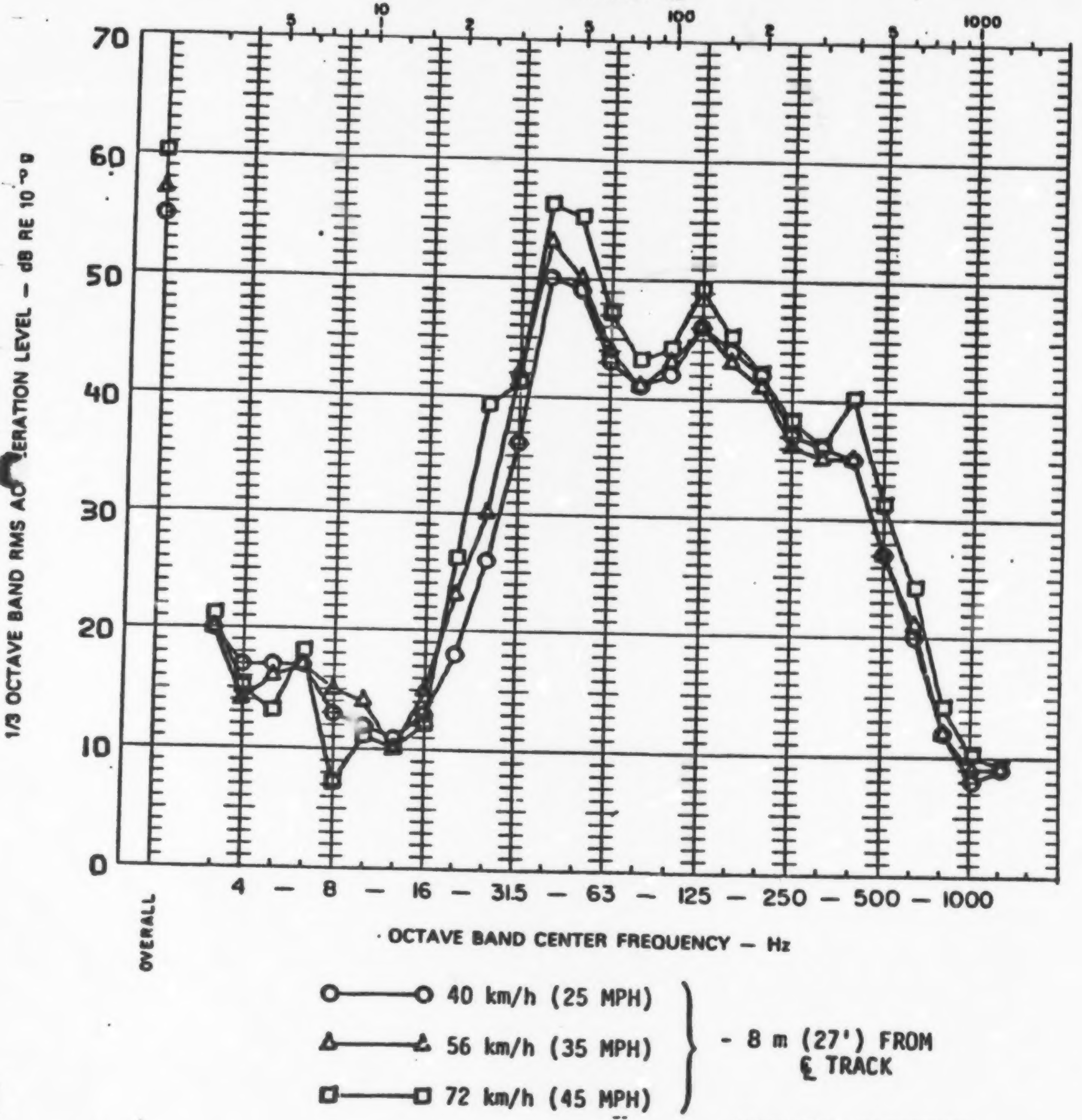

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING AT GRADE

SIGNATURE 40

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	15

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REV. 9/77

TORONTO TRANSIT COMMISSION
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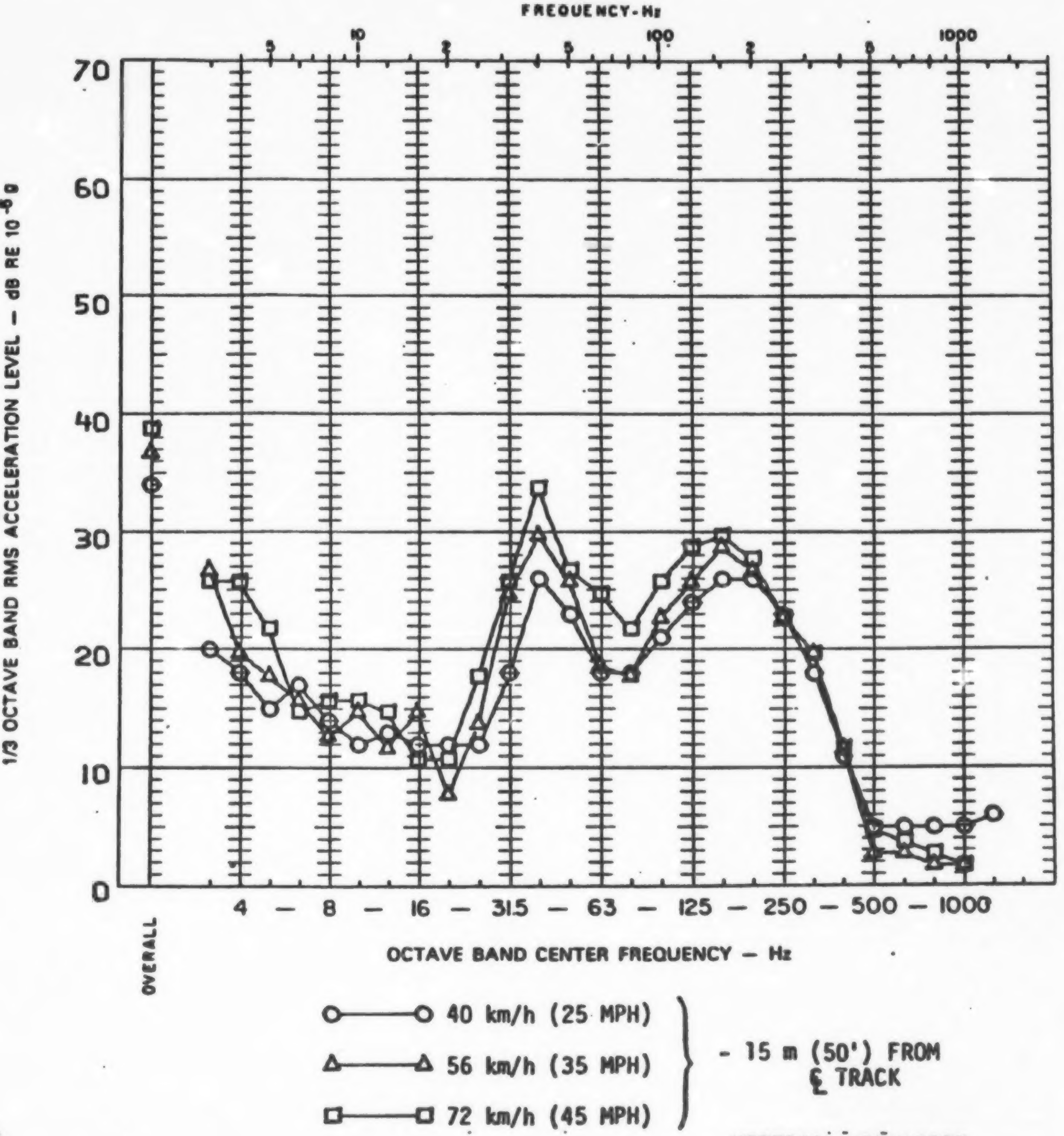

- 15 m (50') FROM
℄ TRACK

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING AT GRADE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	16

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REV. 8/77

TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT

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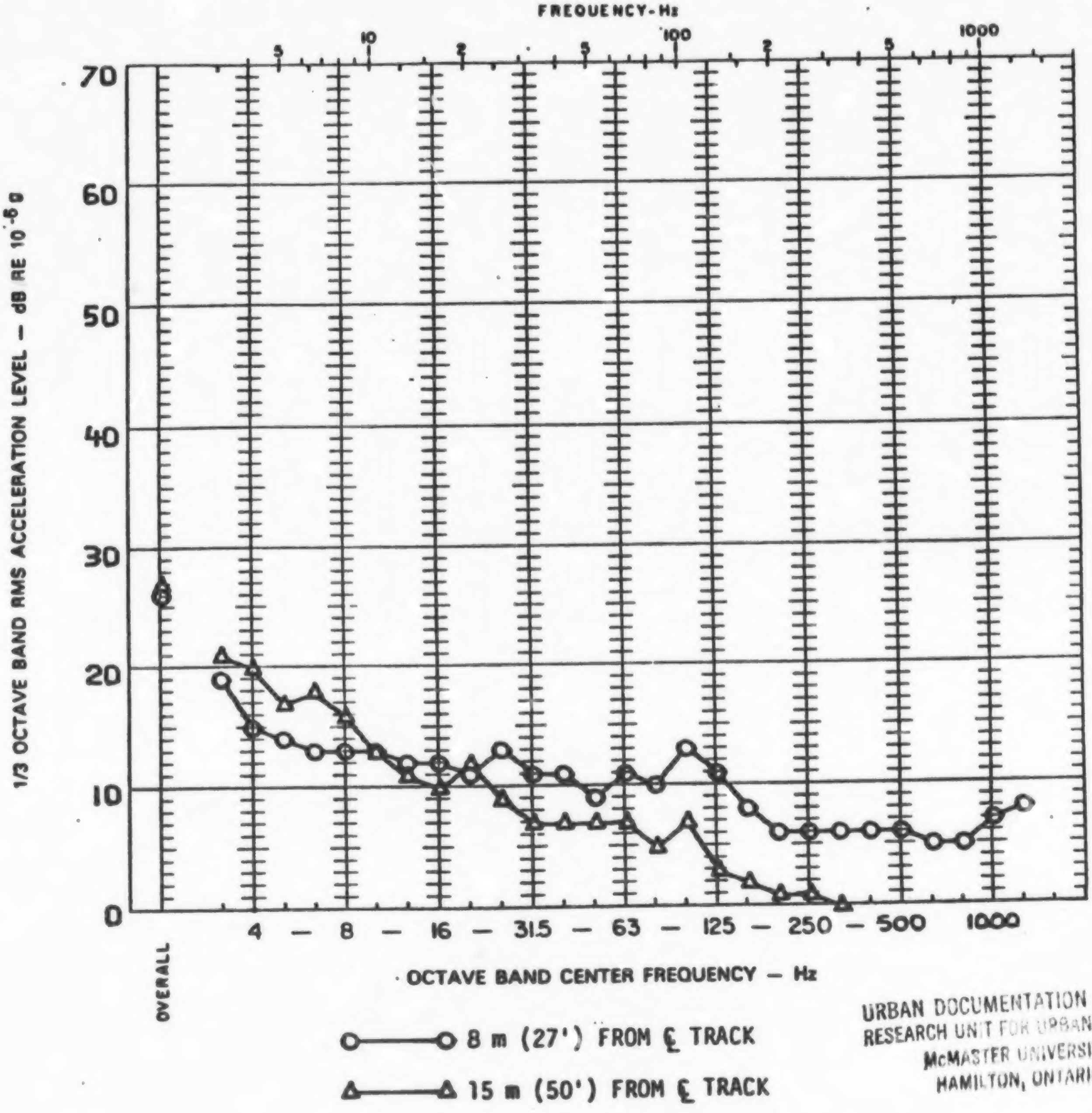

URBAN DOCUMENTATION CENTRE
RESEARCH UNIT FOR URBAN STUDIES
McMASTER UNIVERSITY
HAMILTON, ONTARIO

BACKGROUND VIBRATION

- AT GRADE MEASUREMENT LOCATION

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	17

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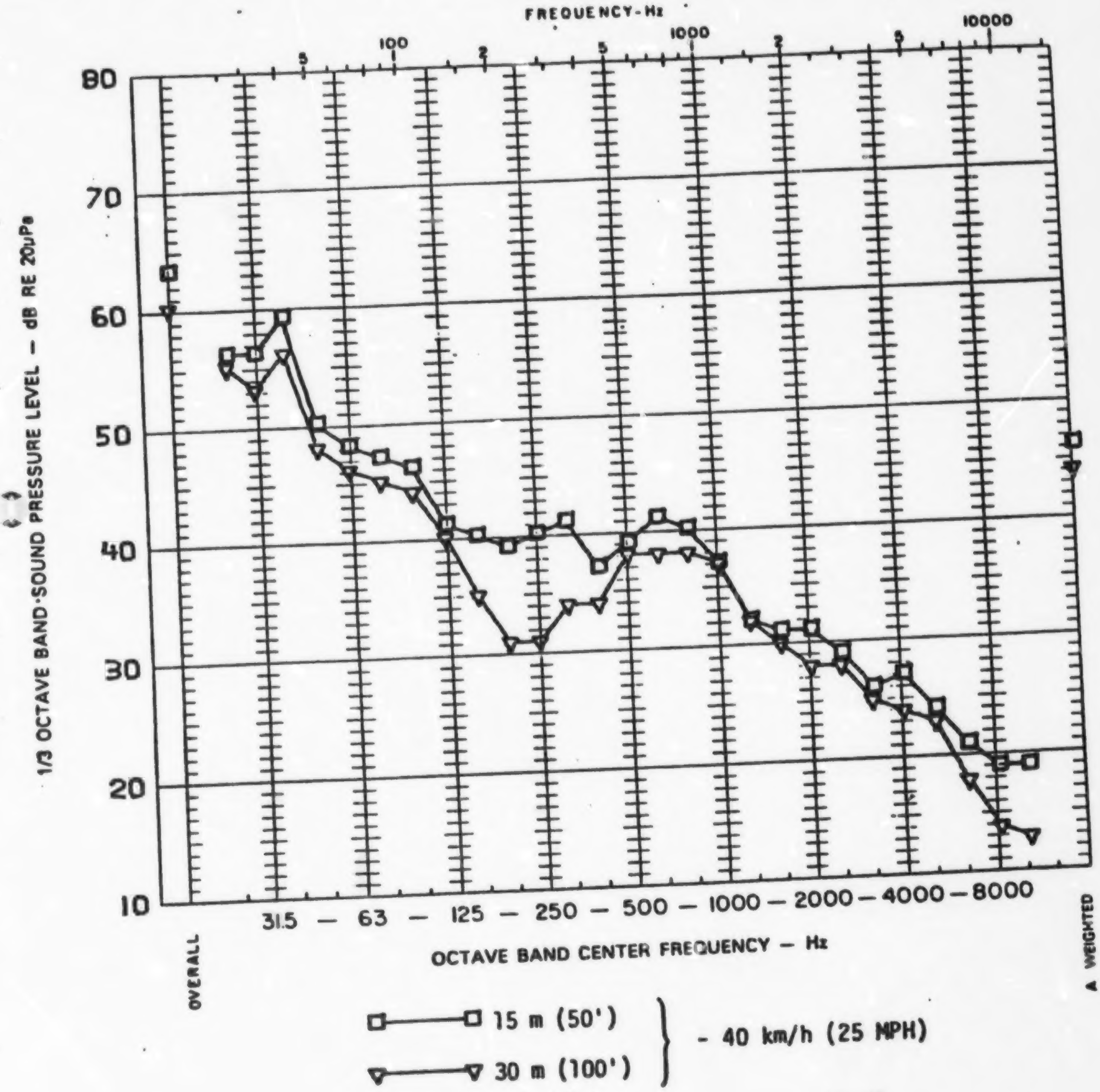
ENGINEERING DEPARTMENT

SOUND DATA SHEET



SOUND

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	18

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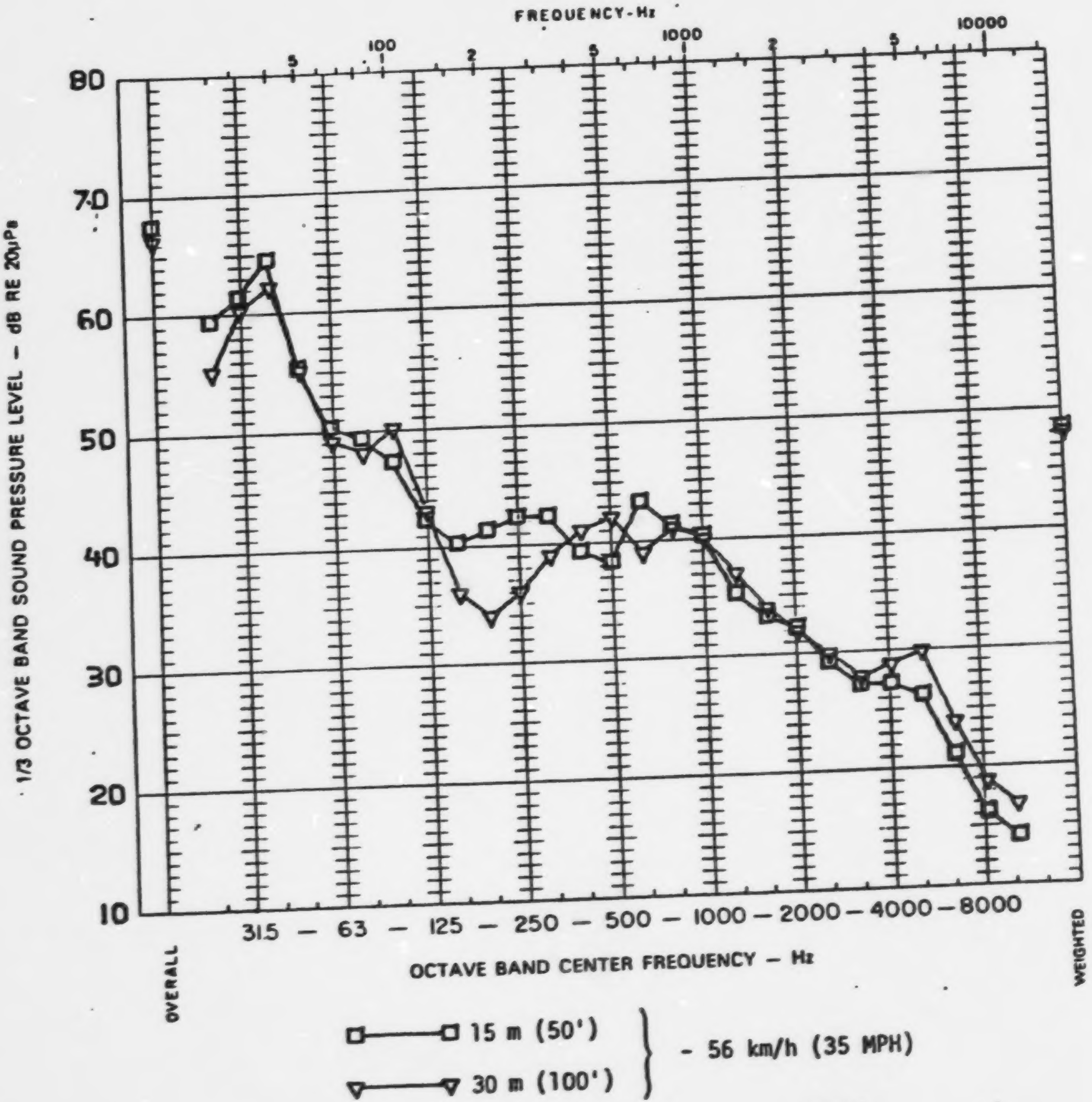
ENGINEERING DEPARTMENT

SOUND DATA SHEET



SOUND

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	19

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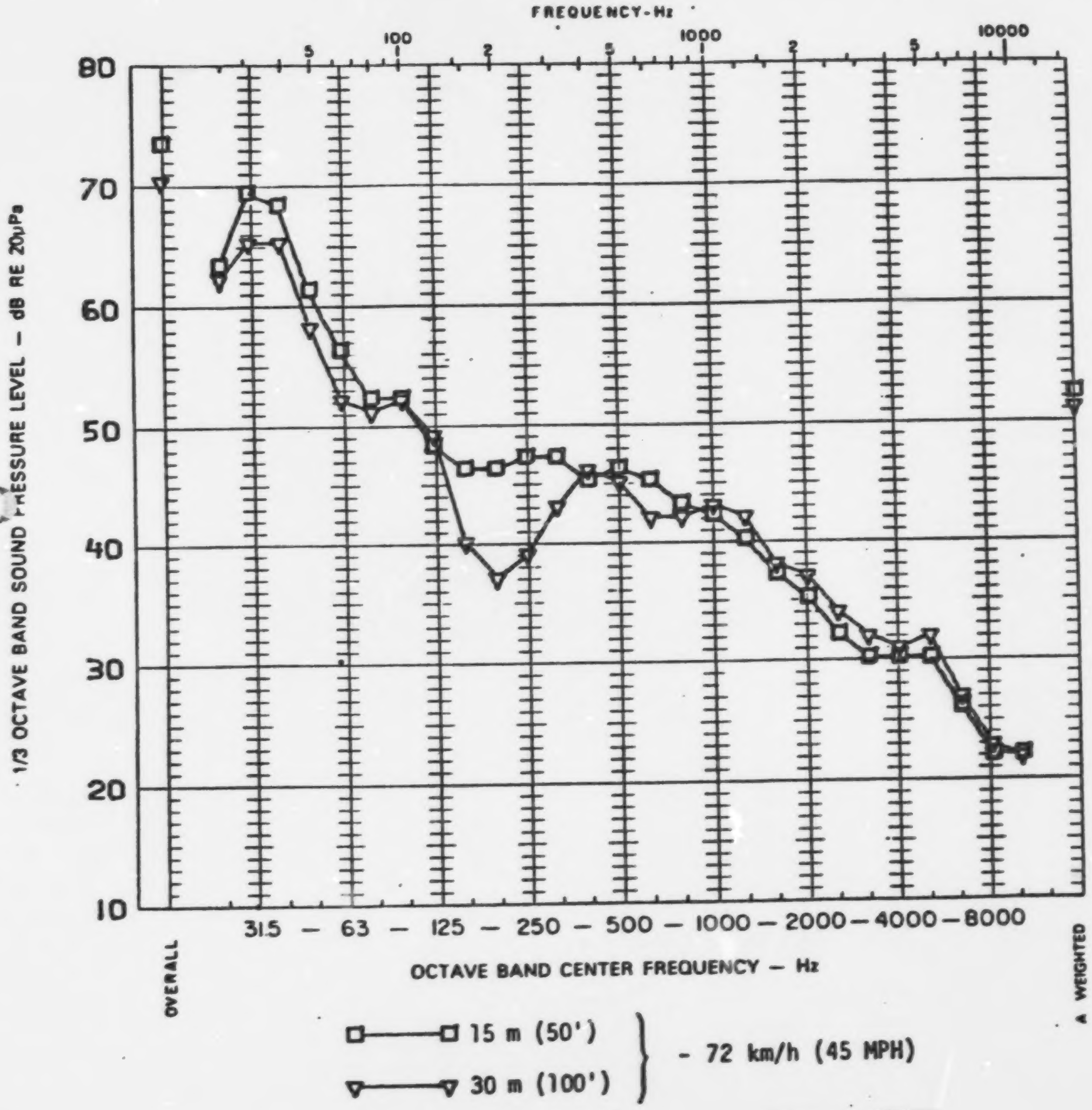

SOUND

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

IGNATURE ____________

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	20

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ENGINEERING DEPARTMENT

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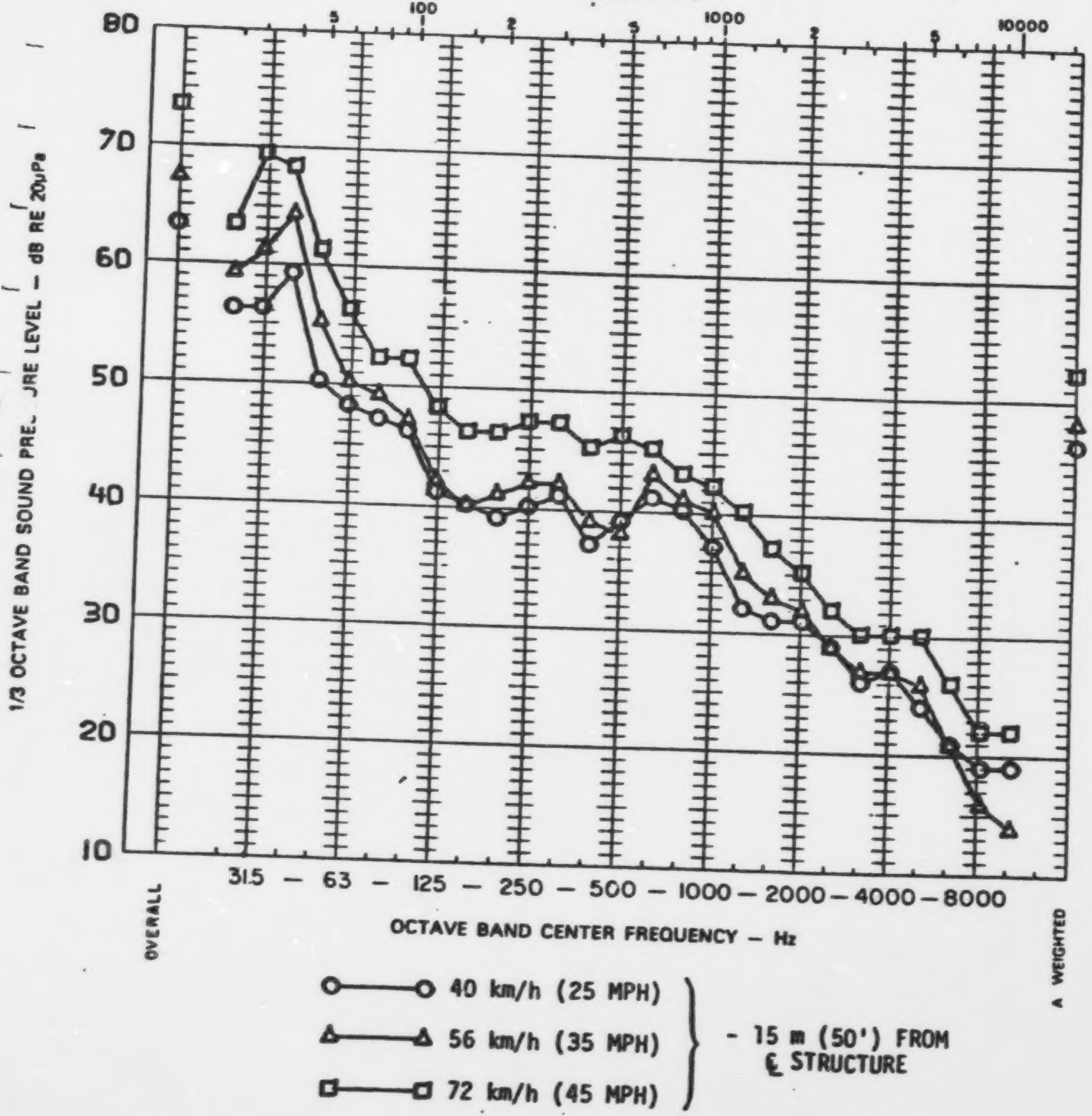

SIGNATURE

SOUND

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

DATE	TITLE	RESEARCH MEMO	FIG NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	21

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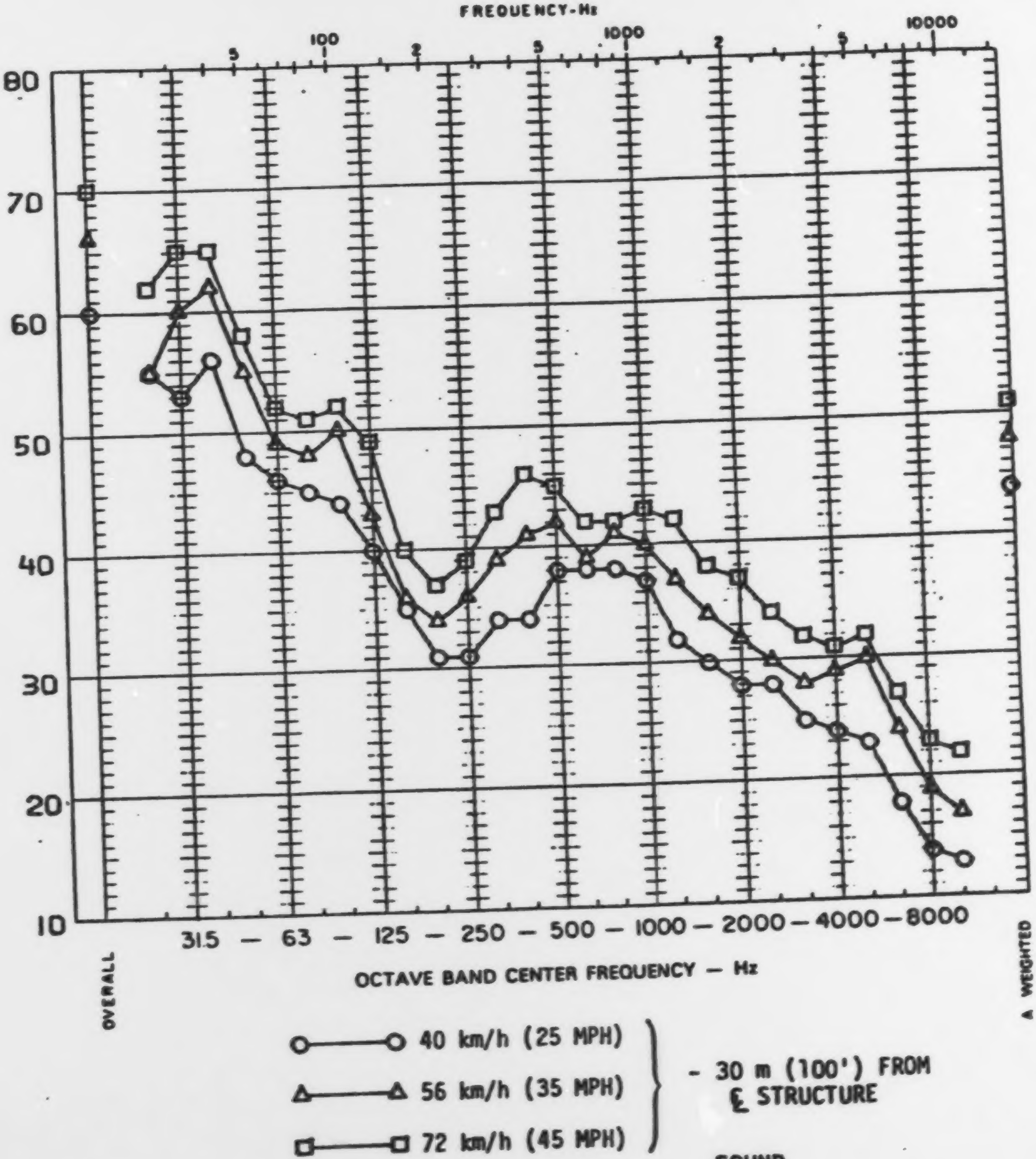

SOUND

SIGNATURE ________ - ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	22

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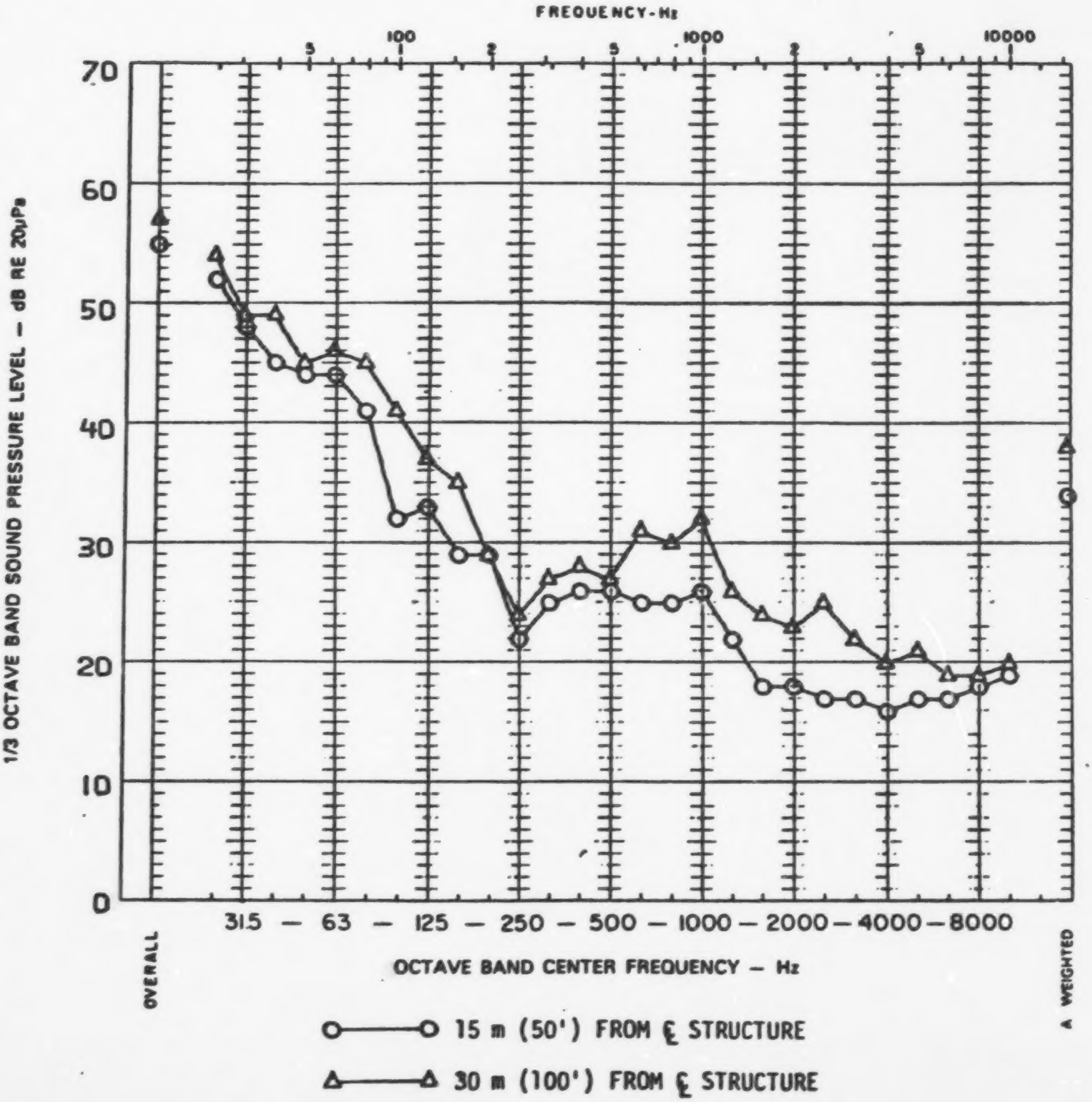
SOUND DATA SHEET



BACKGROUND SOUND

- ELEVATED STRUCTURE MEASUREMENT LOCATION

SIGNATURE ____________

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	23

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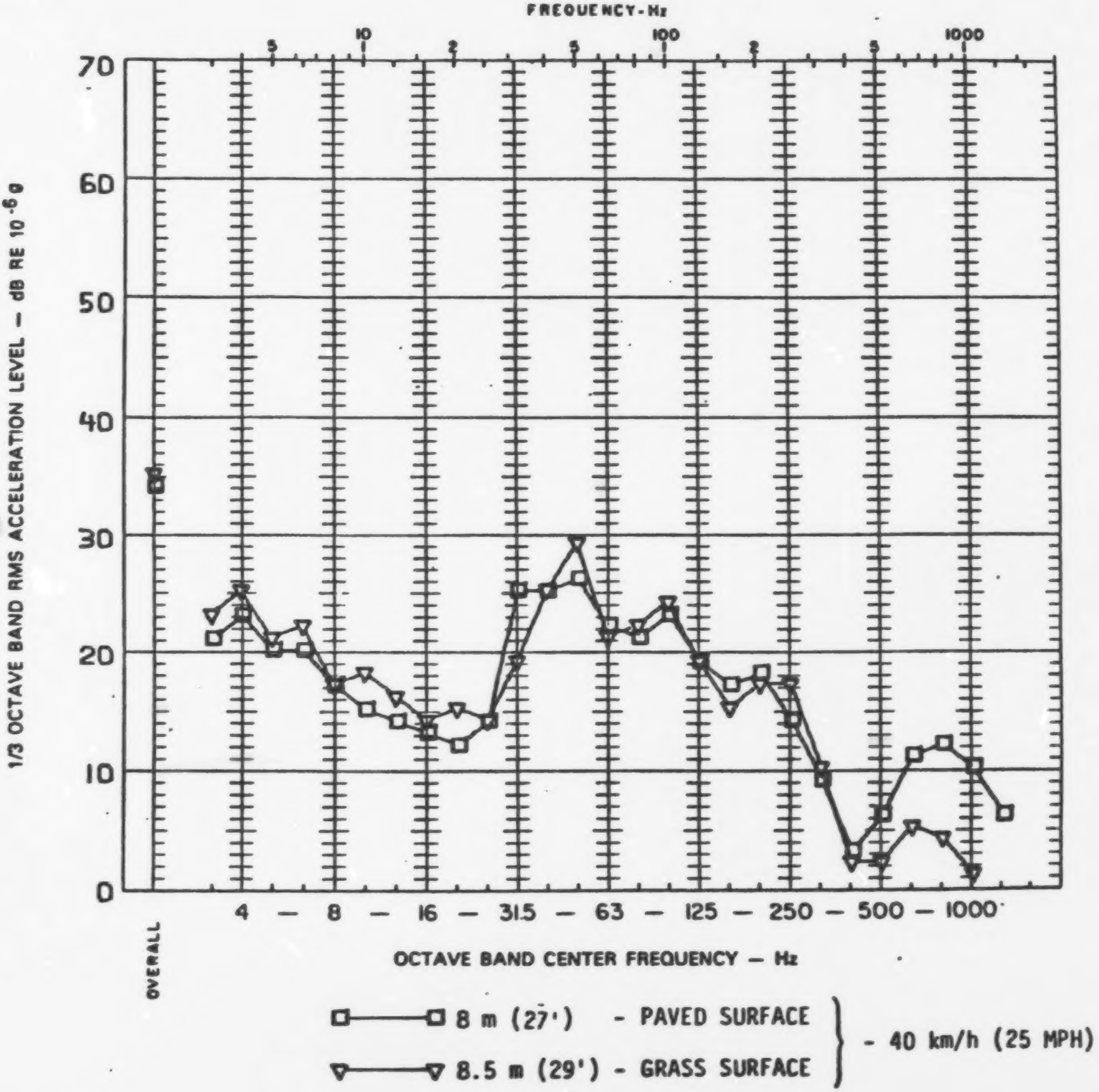
VIBRATION DATA SHEET



VERTICAL VIBRATION

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	24

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ENGINEERING DEPARTMENT

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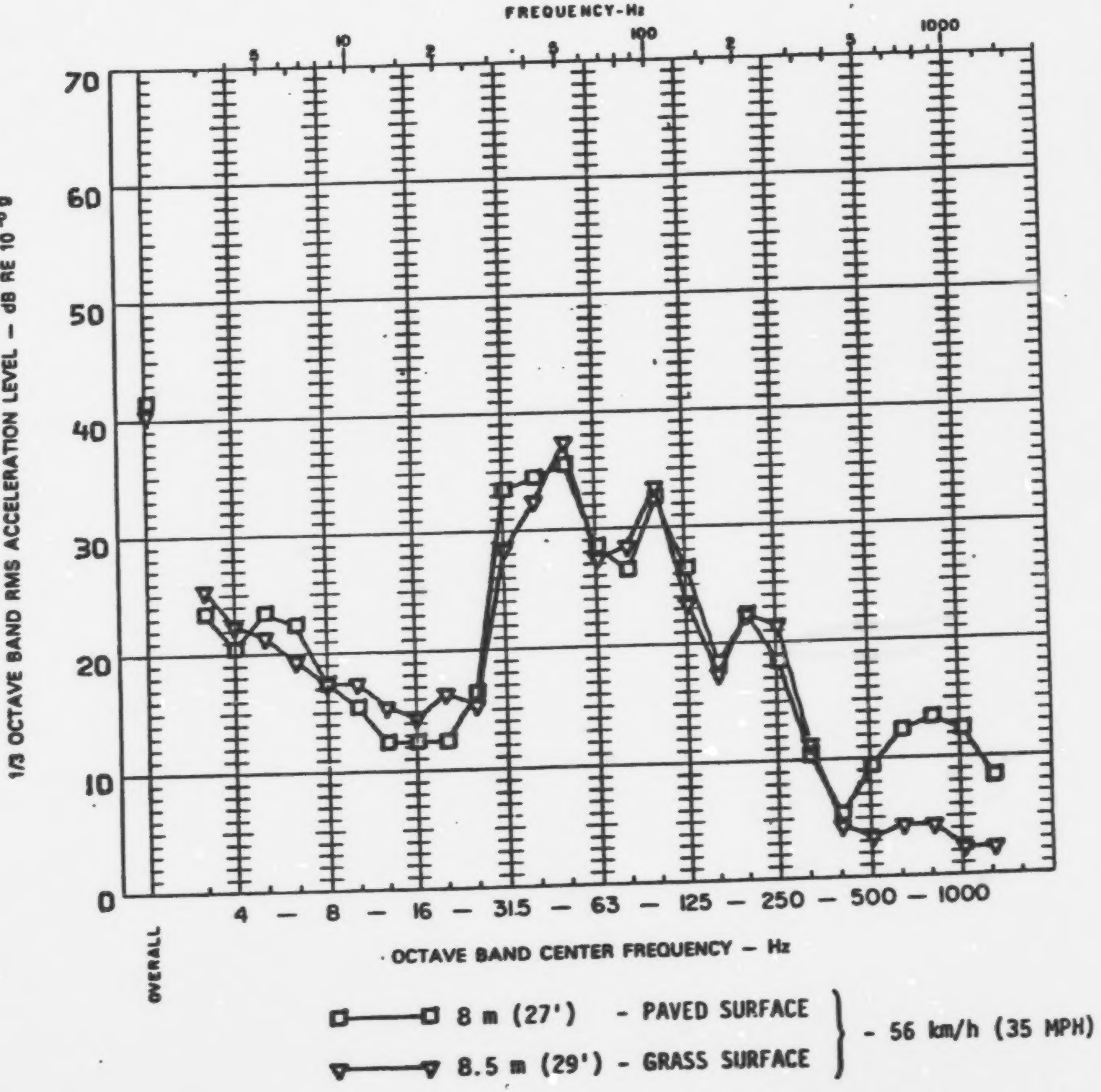

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	25

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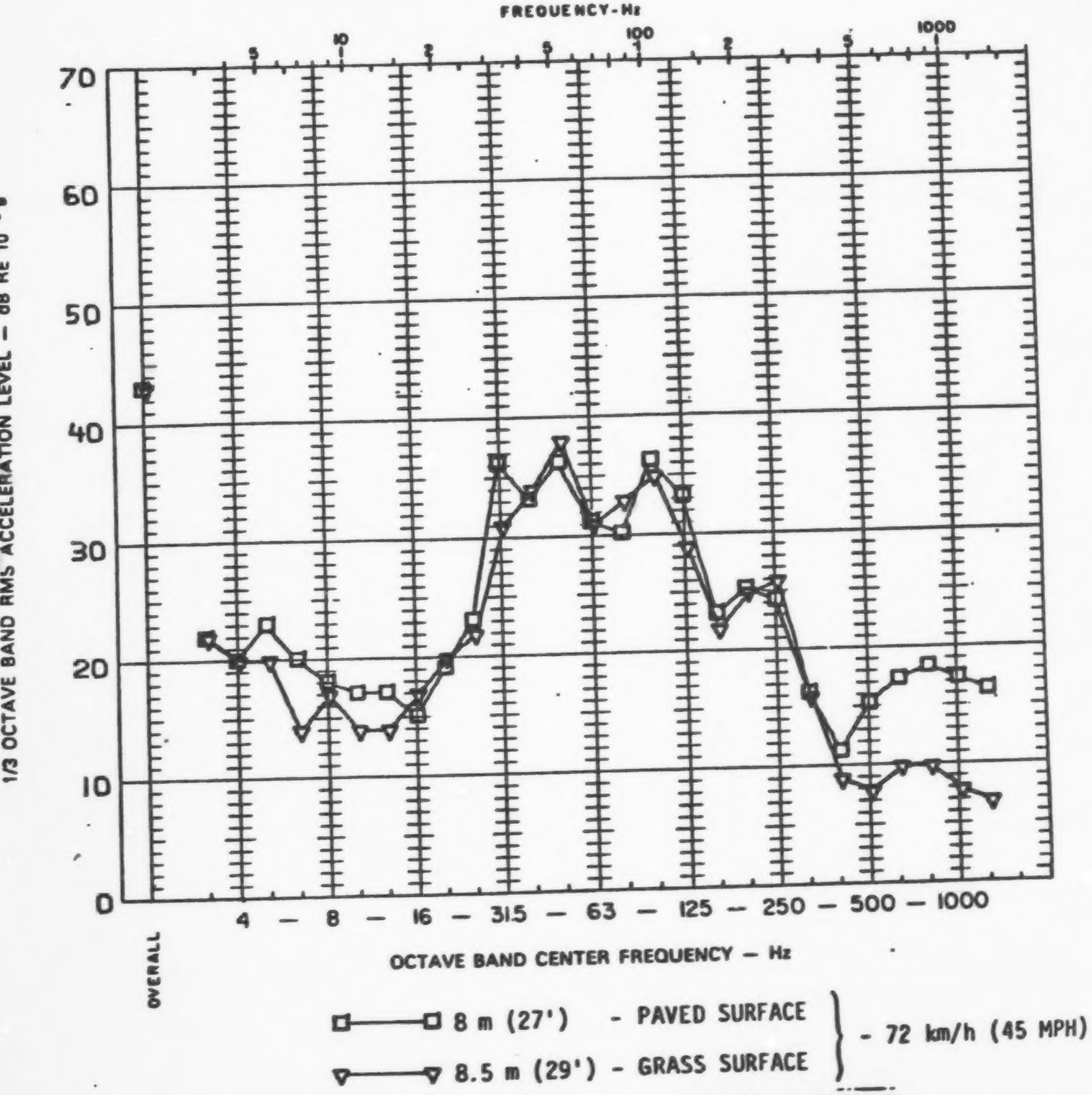
TORONTO TRANSIT COMMISSION
ENGINEERING DEPARTMENT

VIBRATION DATA SHEET



VERTICAL VIBRATION

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

NATURE ____________________

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	26

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ENGINEERING DEPARTMENT

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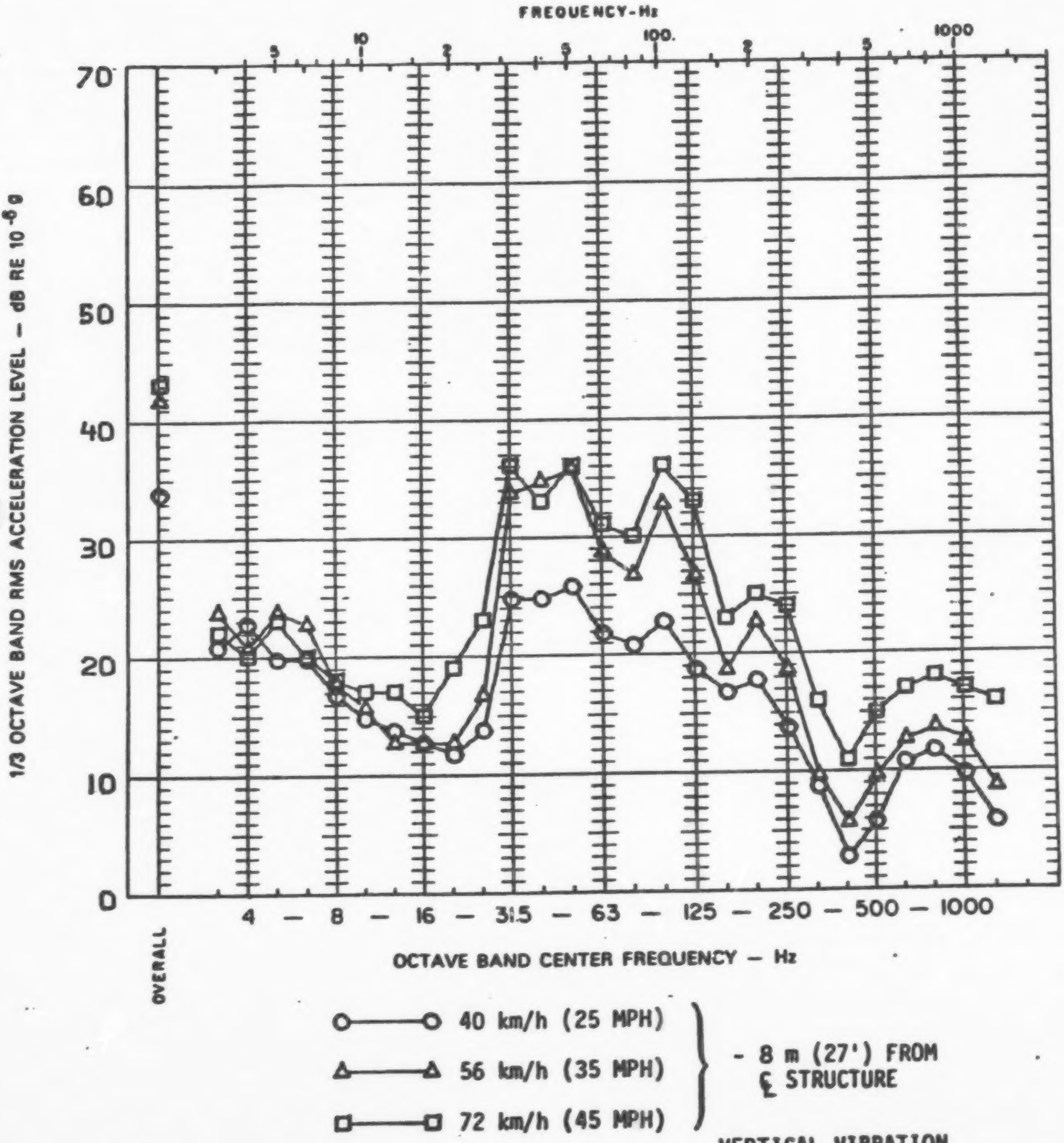

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	27

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REV. 8/77

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ENGINEERING DEPARTMENT

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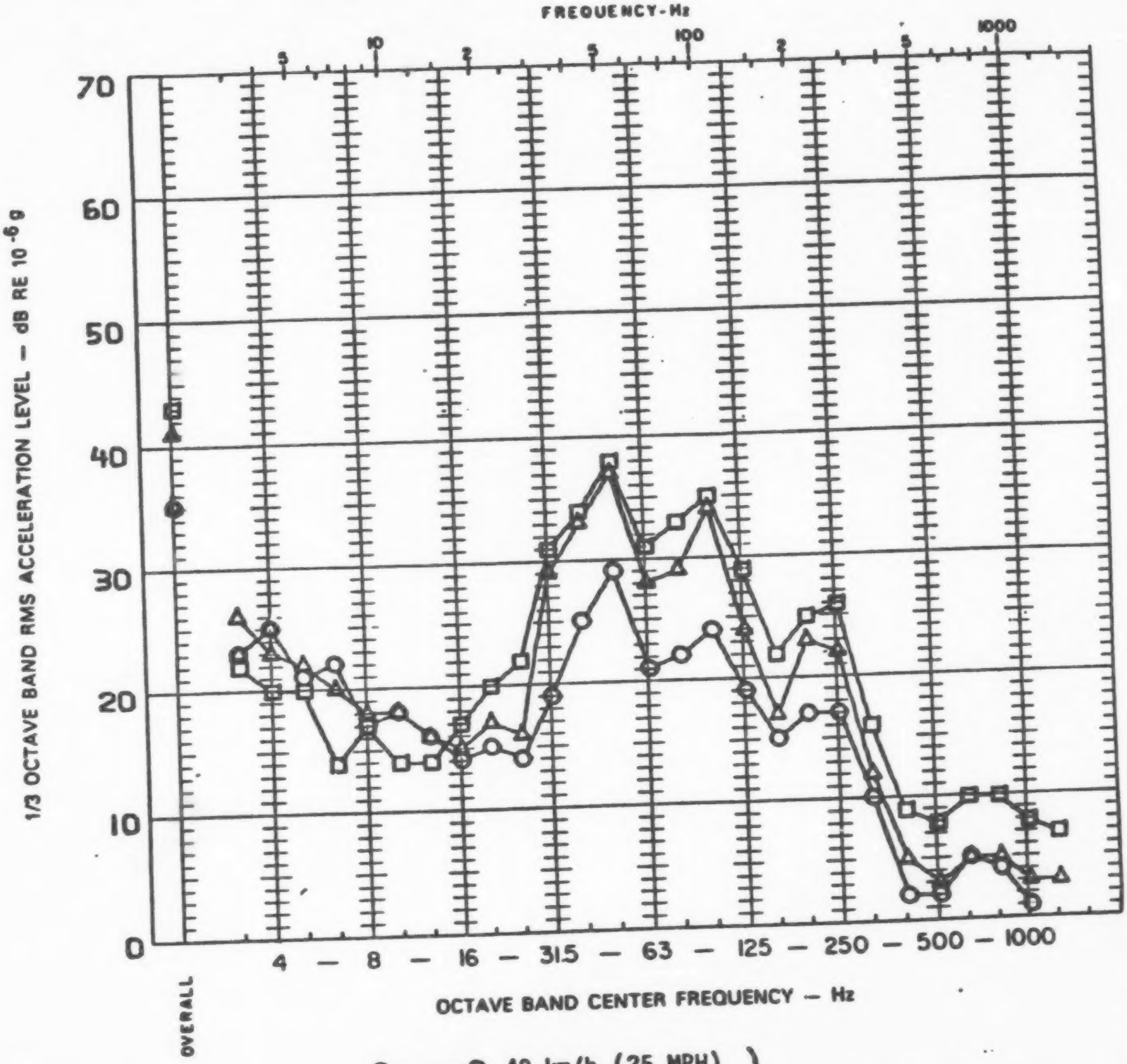

○———○ 40 km/h (25 MPH)
△———△ 56 km/h (35 MPH)
□———□ 72 km/h (45 MPH)

- 8.5 m (29') FROM ℄ STRUCTURE

VERTICAL VIBRATION

- ICTS VEHICLE OPERATING ON ELEVATED STRUCTURE

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	28

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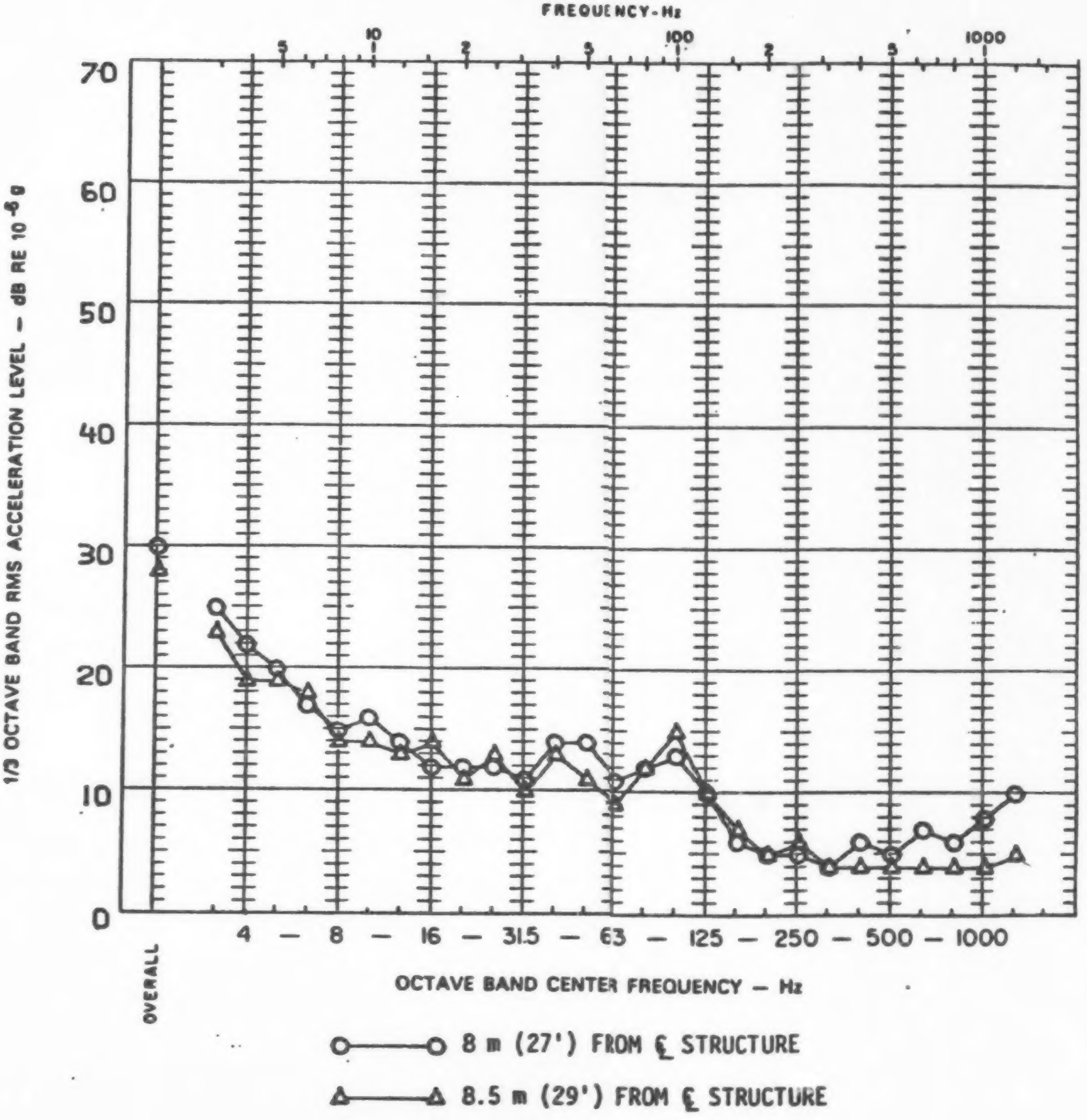


BACKGROUND VIBRATION
- ELEVATED STRUCTURE MEASUREMENT LOCATION

SIGNATURE

DATE	TITLE	RESEARCH MEMO	FIG. NO.
JUNE 1981	ICTS SOUND & VIBRATION EVALUATION	693	29

APPENDIX 2

METRO CANADA LIMITED
STEEL GUIDEWAY STUDY
NOISE/VIBRATION BASELINE DATA
KINGSTON, ONTARIO
MARCH 9, 1981

RECEIVED
WILSON, IHRIG & ASSOCIATES
MAR 11 1981
ACOUSTICAL CONSULTANTS

metro canada
limited

TO: H. Ledsham

DATE: 09/03/81

SUBJECT: STEEL GUIDEWAY STUDY - NOISE/VIBRATION BASELINE DATA

REFERENCE No: 290 ENG 1 155

Data for use during evaluation of comparative noise radiation characteristics for ICTS concrete and proposed steel box section guideway is enclosed. This data has been collected during the ICTS development/test program and is therefore not to be considered as input to an environmental impact assessment presentation. Collection and analysis of data with system configurations which are more representative of revenue conditions are scheduled for completion in the near future.

All data presented is for single vehicle operation on solid steel wheels with Hixson rail fasteners.

Wheel/Rail Noise and Vibration Source

Fig. 2 is an octave analysis of the 15 m sideline noise as recorded at location (a) of Fig. 1. Pass-by speeds are 36-54 and 72 km/hr on recently polished rail.

Fig. 3 (a), (b) and (c) are presented only as a comparison between sideline noise levels at locations (a) and (k) of Fig. 1, i.e. 15 m distance at guideway height and at 1.5 m above ground level. These levels do not compare with those of Fig. 2 because they were recorded prior to implementation of a running rail surface condition evaluation program.

Fig.'s 4, 5 and 6 are vibration levels recorded on the guideway deck, sidewall and box beam during passage of a single vehicle at 36, 54 and 72 km/hr.

Propulsion Noise and Vibration Source

ICTS is unique in that propulsion noise and vibration is generated due to reaction of the guideway structure to linear induction motor thrust forces.

Fig. 7 is a presentation of sideline noise level at location (a) at a distance of 15 m from the elevated guideway. The vehicles was coasted along the guideway at 36, 54 and 72 km/hr and full power applied to the propulsion system when passing the microphone.

Fig.'s 8 and 9 present guideway deck, sidewall and box beam vibration levels during vehicle acceleration from stationary past the monitor location. Speed at the transducer was approximately 18 km/hr.

These propulsion vibration levels were measured for a propulsion system which will not be part of a revenue configuration and are enclosed to demonstrate that an ICTS could possibly generate excitation forces in a frequency region which is critical with reference to steel guideway structural response.

G. Unsworth L. Gray

GU/vk

Att.

CC: L. Gray - MCL Kingston
L. McCartney - Cole Sherman & Associates Ltd.
R. Griebenow - ABAM
S. Wolfe - Wilson Ihrig
R. Murray - MCL Hamilton
J. Collins - MCL Hamilton
Chrono
CFD - 78.5.2

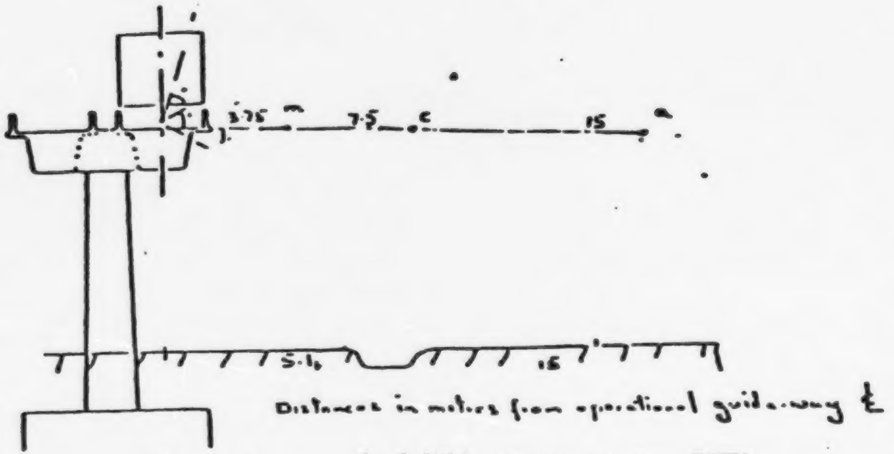
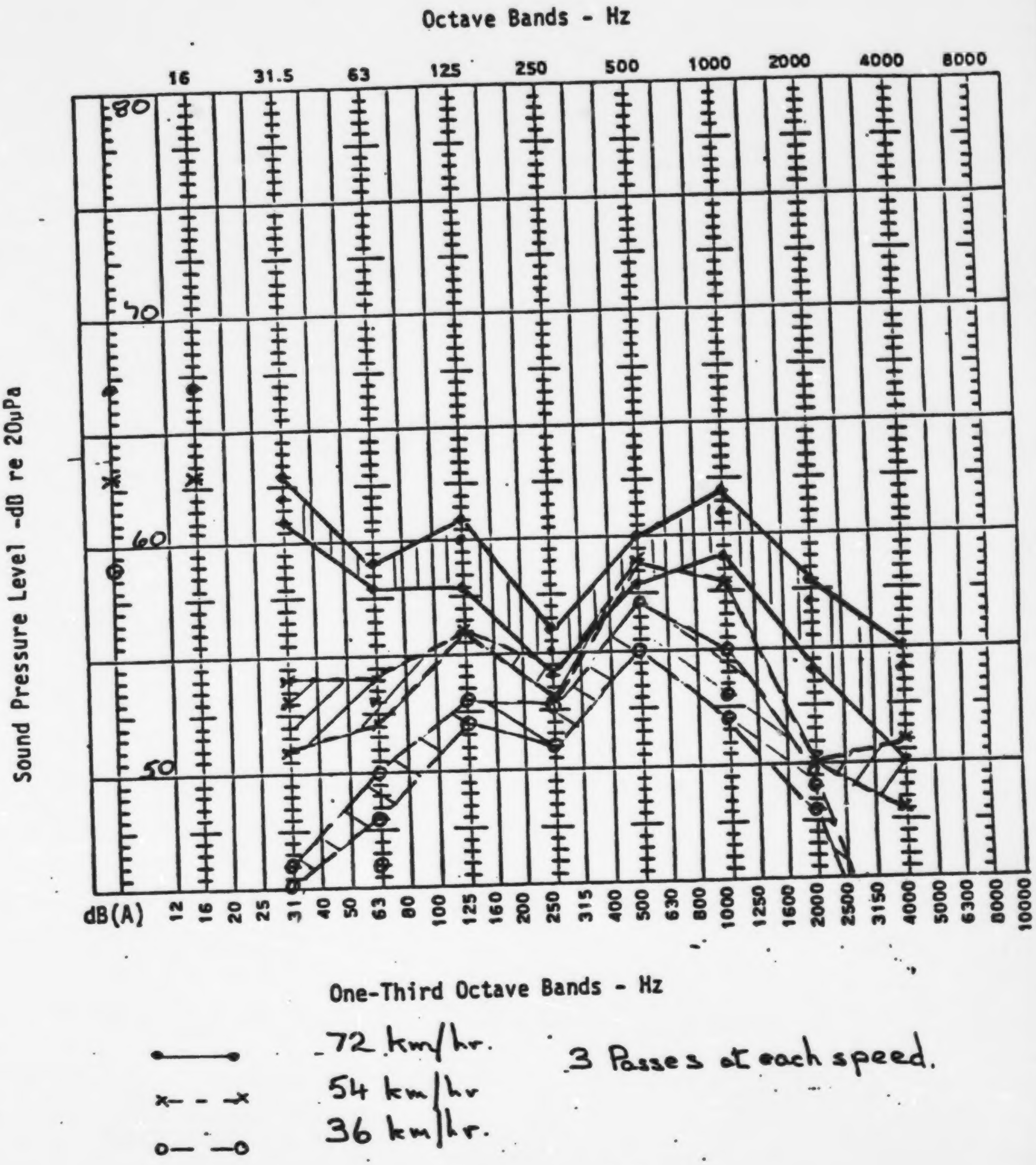

3.75
7.5
15
5.1
15
Distances in meters from operational guideway ℄

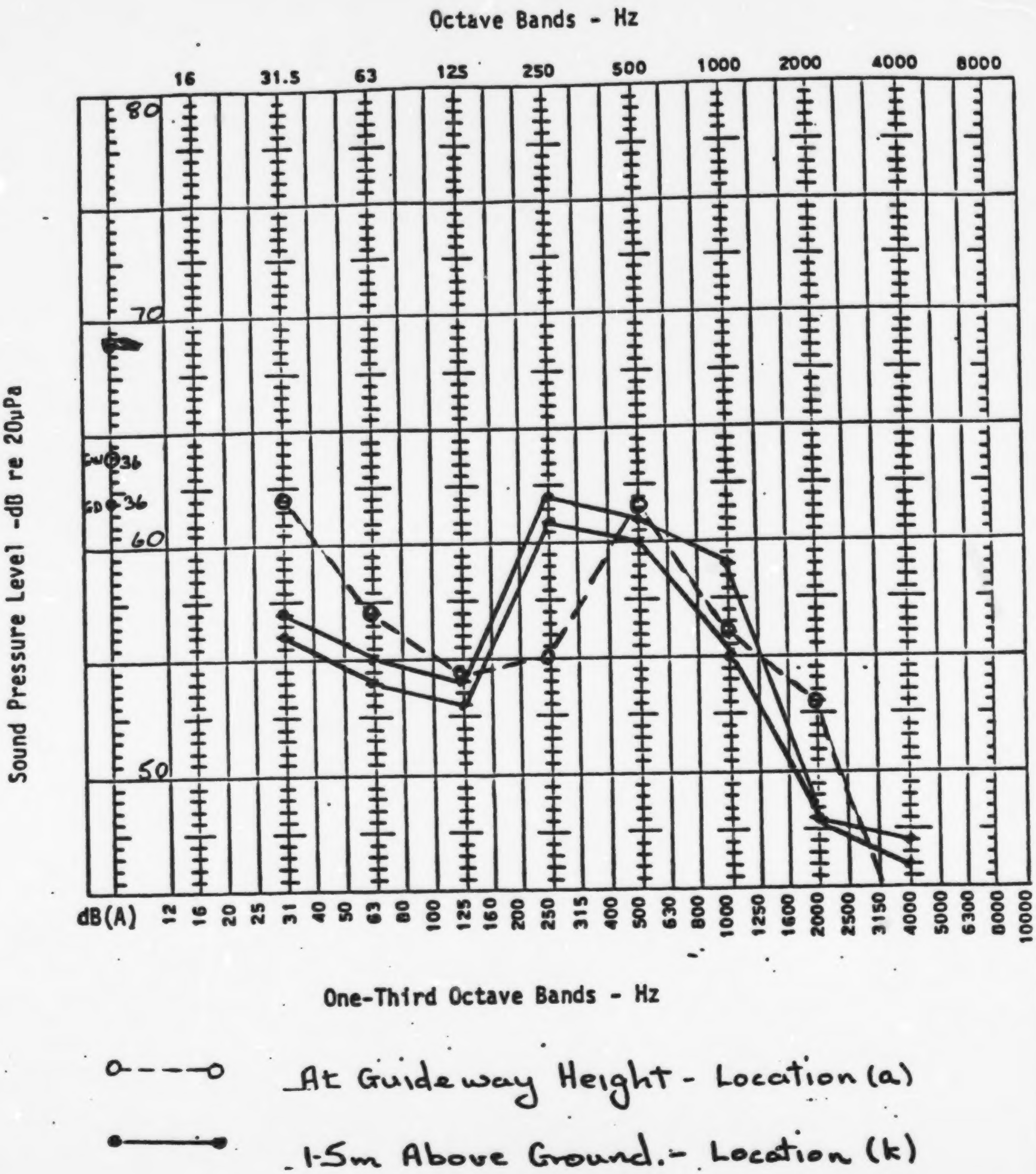
Figure 1 Cross-Section of Elevated Guideway Area Showing Microphone Locations



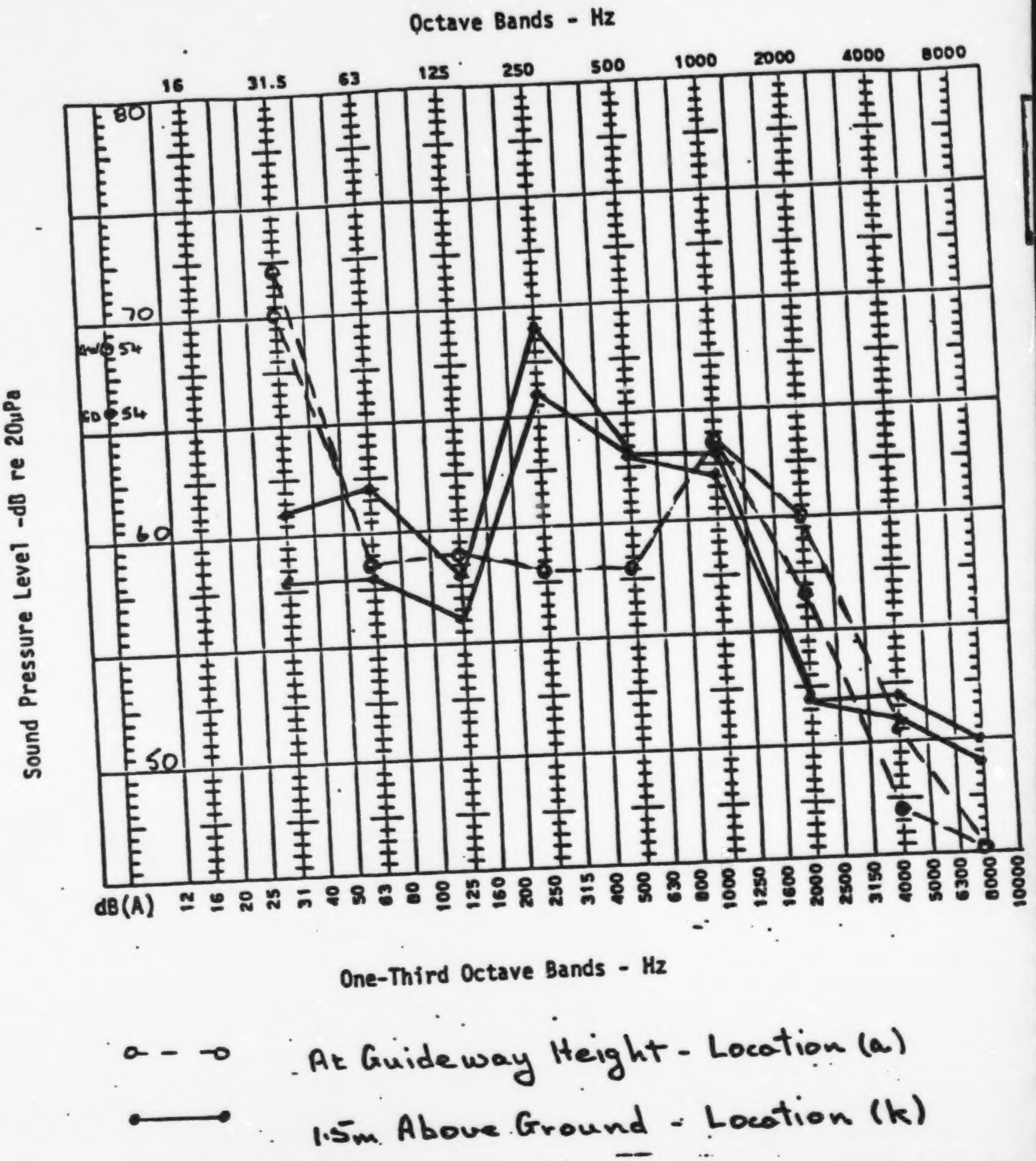
3 Passes at each speed.

Location (a).

FIG. 2. 15M SIDE-LINE NOISE at G.W. HEIGHT - ELEVATED GUIDEWAY



(Before Rail Polishing)
FIG. 3(a) 15 M SIDE-LINE NOISE at
ELEVATED GUIDEWAY — 36 km/hr



(Before Rail Polishing)

FIG. 3(b) 15M SIDE-LINE NOISE
- ELEVATED GUIDEWAY - 54 km/hr

NOISE - ELEVATED GUIDEWAY - 54 km

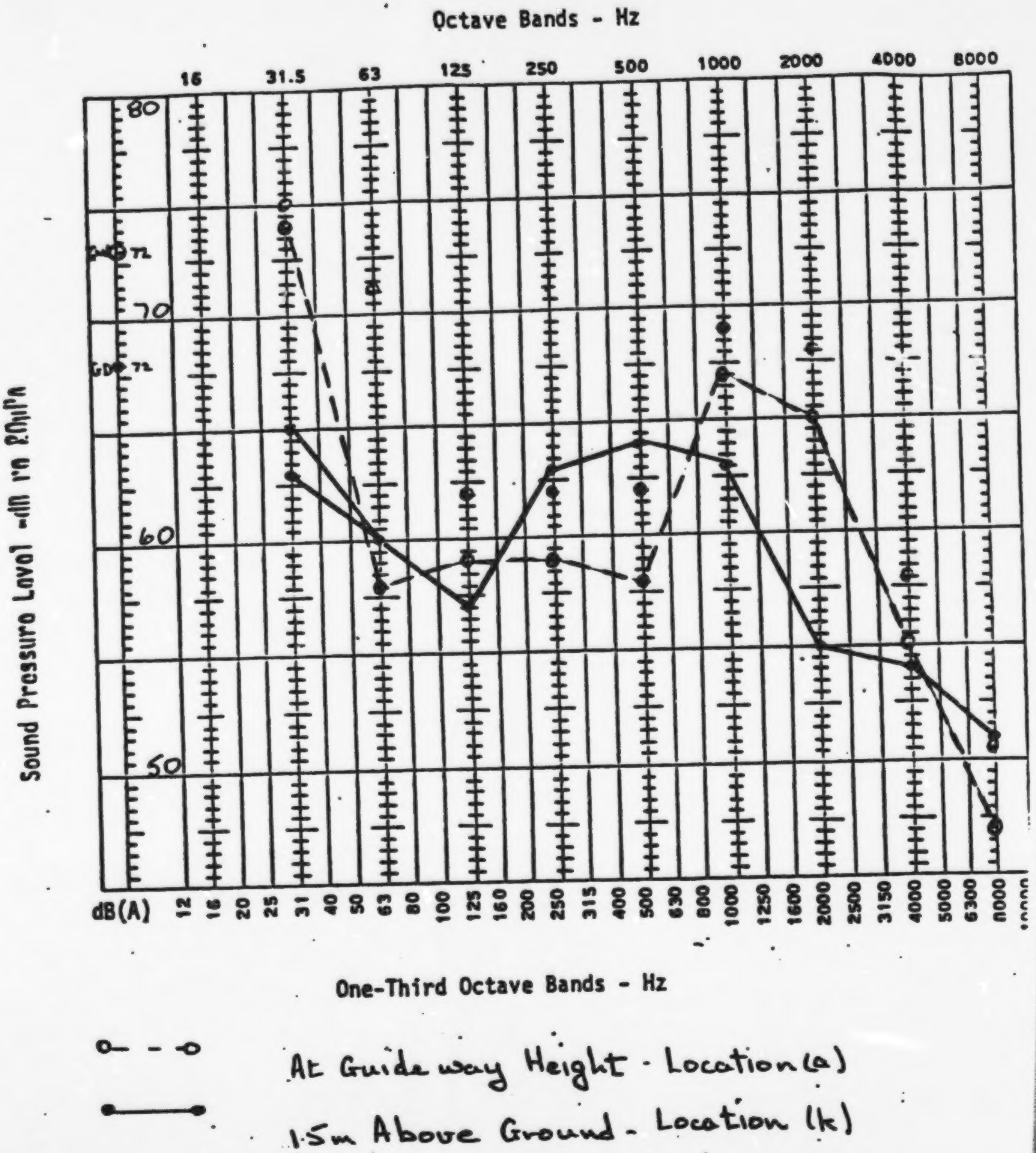


Fig. 3 (c) 15M SIDE-LINE NOISE - ELEVATED GUIDEWAY - 72 km/hr (Before Rail Polishing)

LINE NOISE - ELEVATED GUIDE-WAY - 72 km/hr

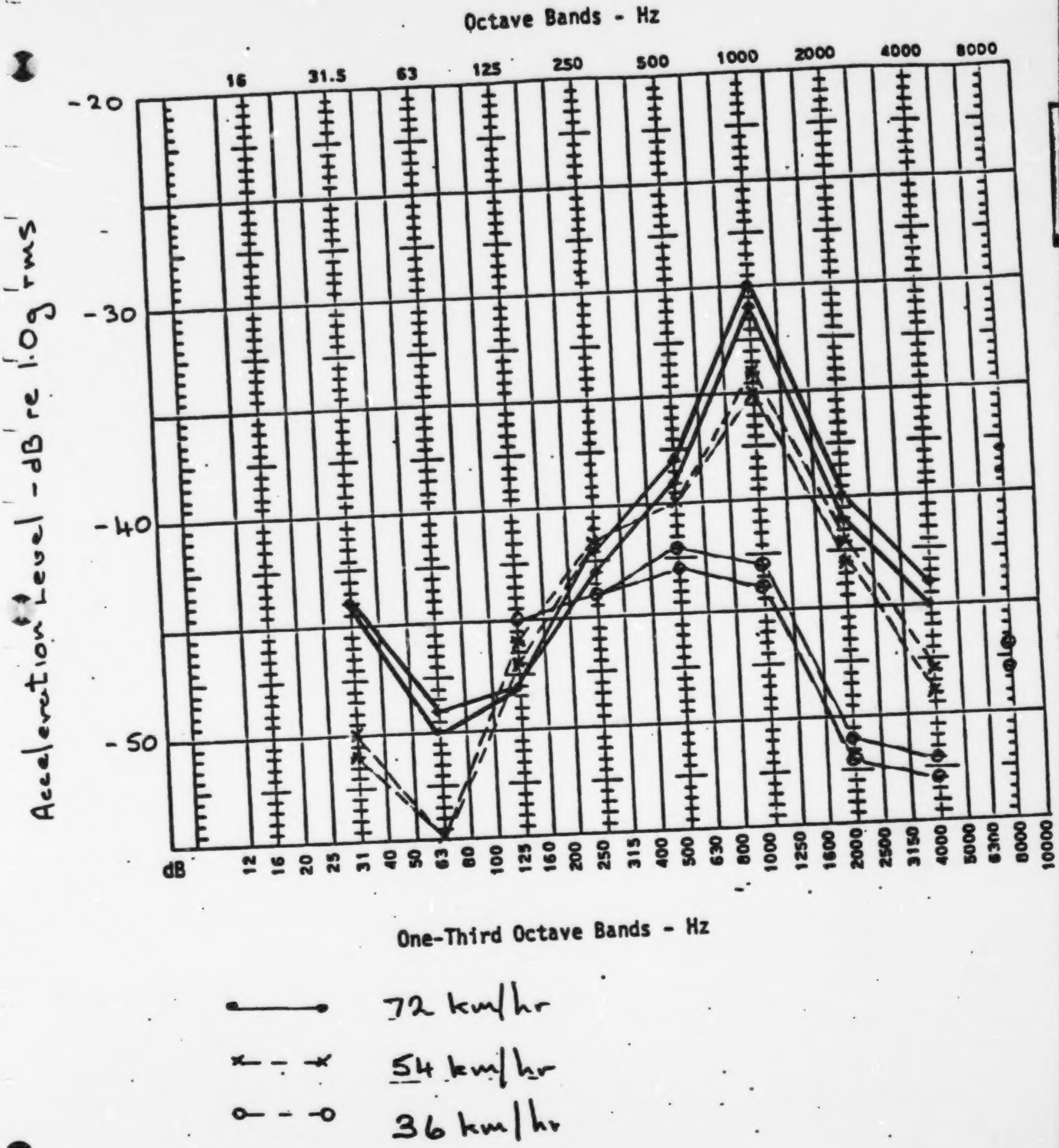


FIG.4 DECK VIBRATION - ELEVATED GUIDEWAY

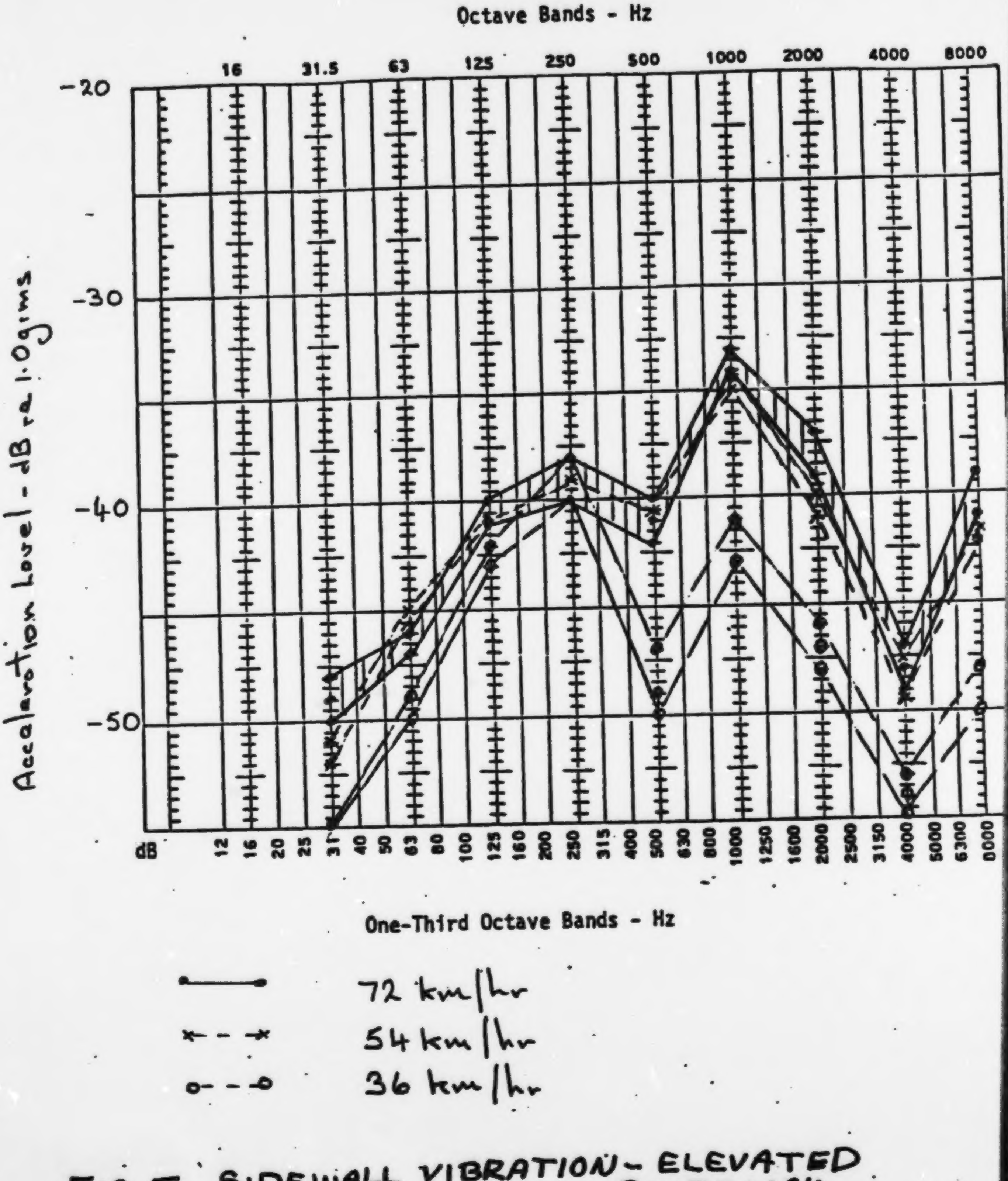


FIG.5 SIDEWALL VIBRATION - ELEVATED GUIDEWAY

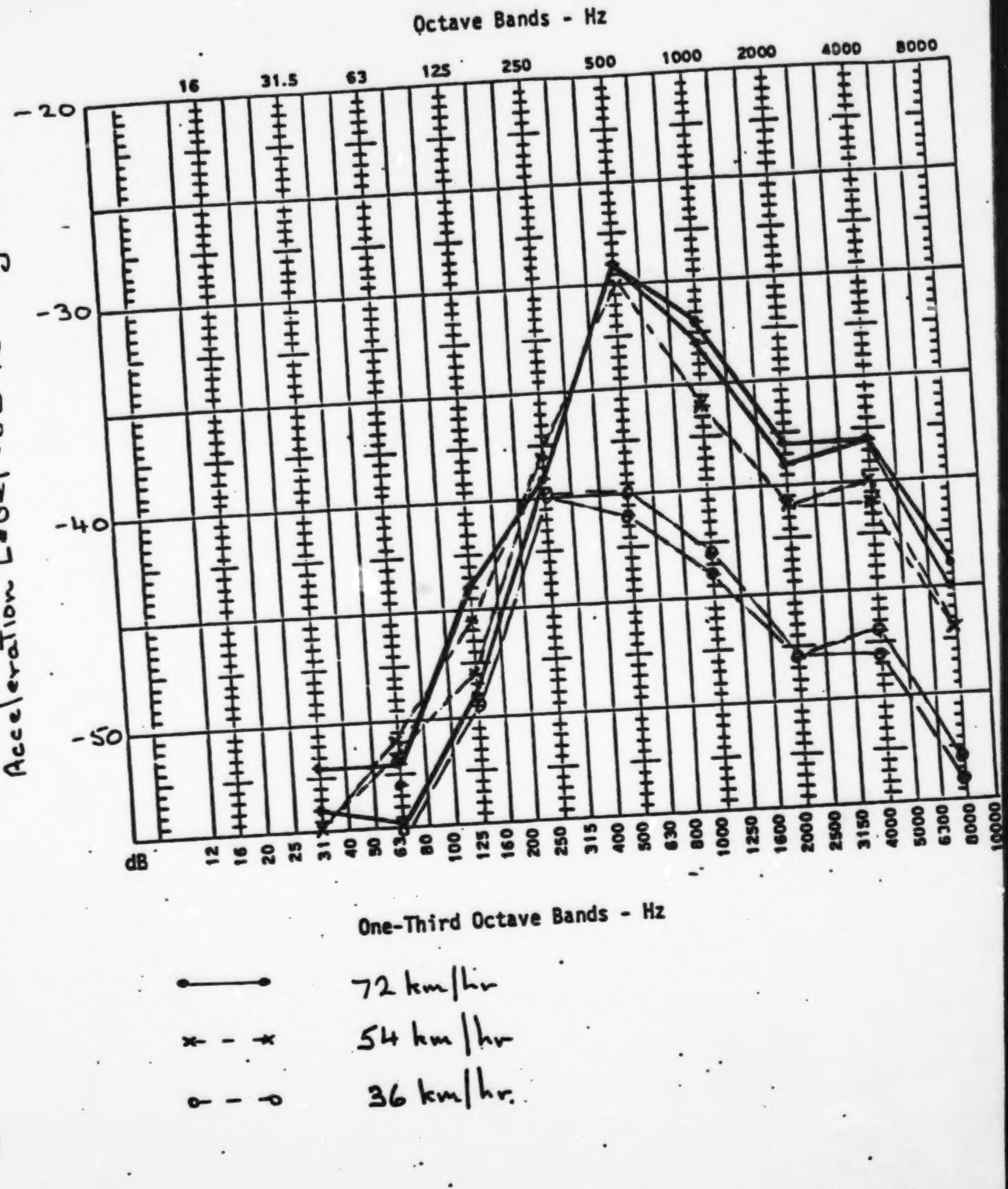


FIG. 6 – BOX BEAM

LATERAL VIBRATION – ELEVATED GUIDE WAY.

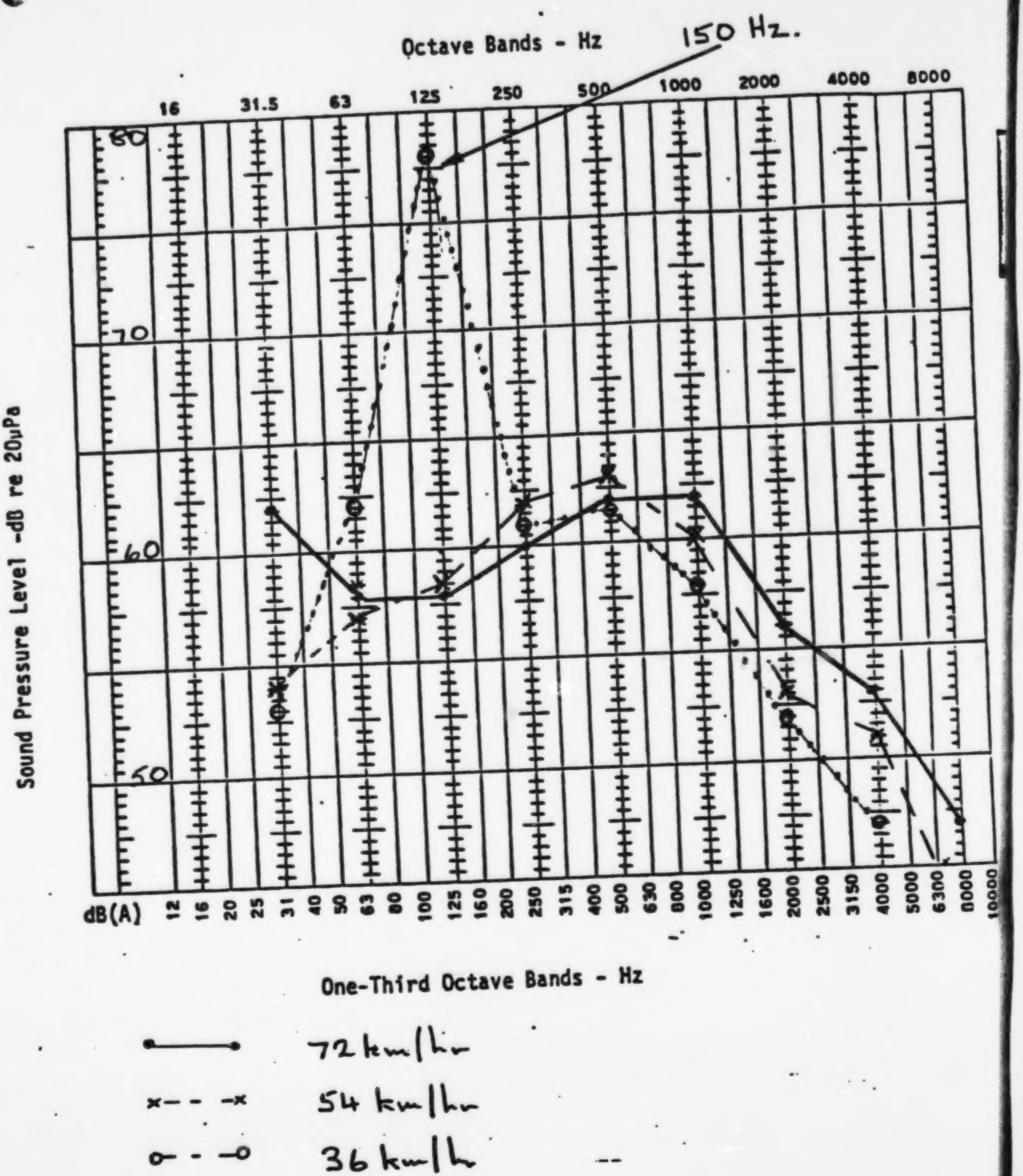


FIG.7- 15M SIDE-LINE NOISE— ELEVATED GUIDEWAY-VEHICLE ACCEL^{N}.

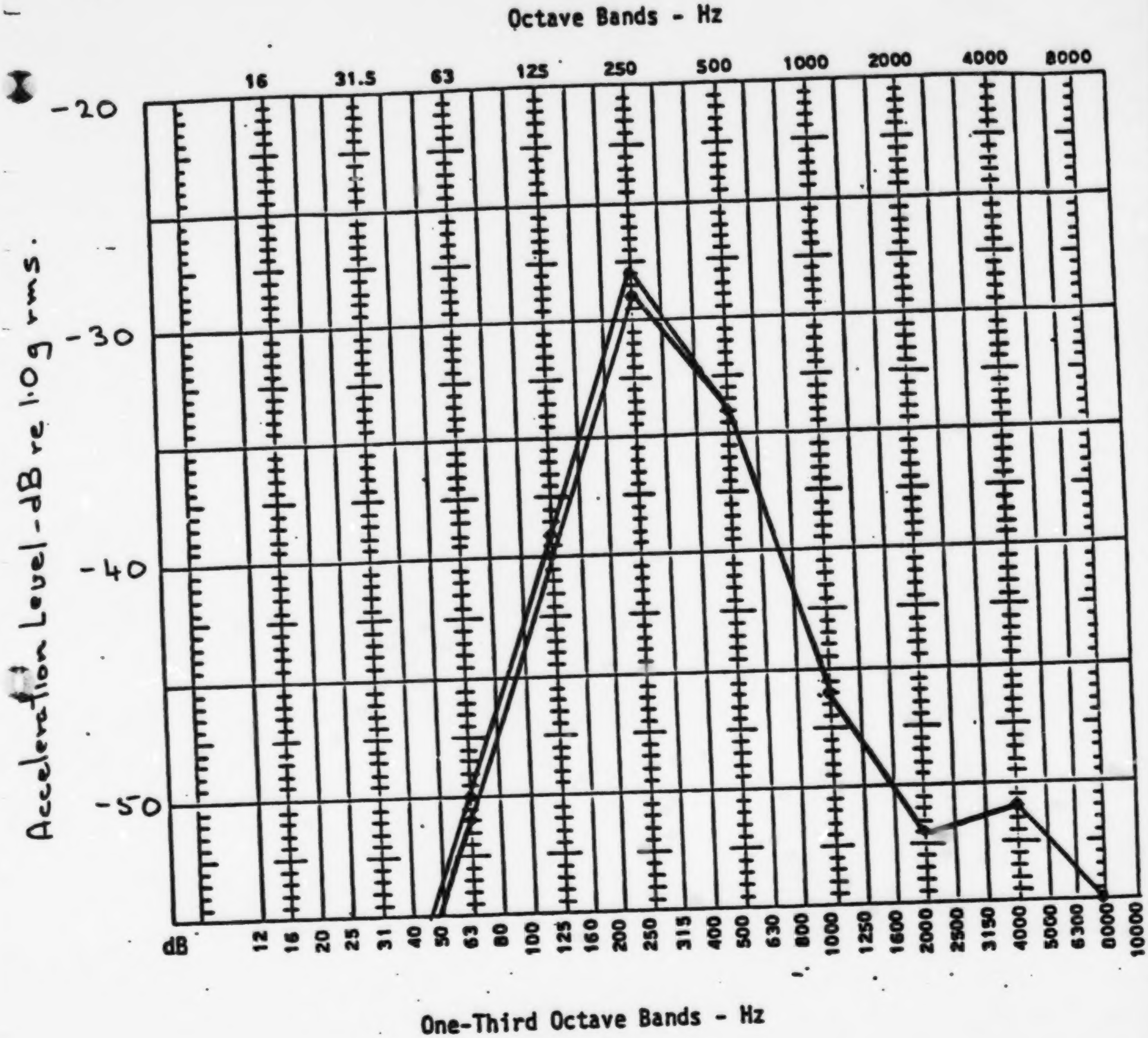


FIG.8 DECK VIBRATION. ELEVATED GUIDEWAY - ACCELERATING.

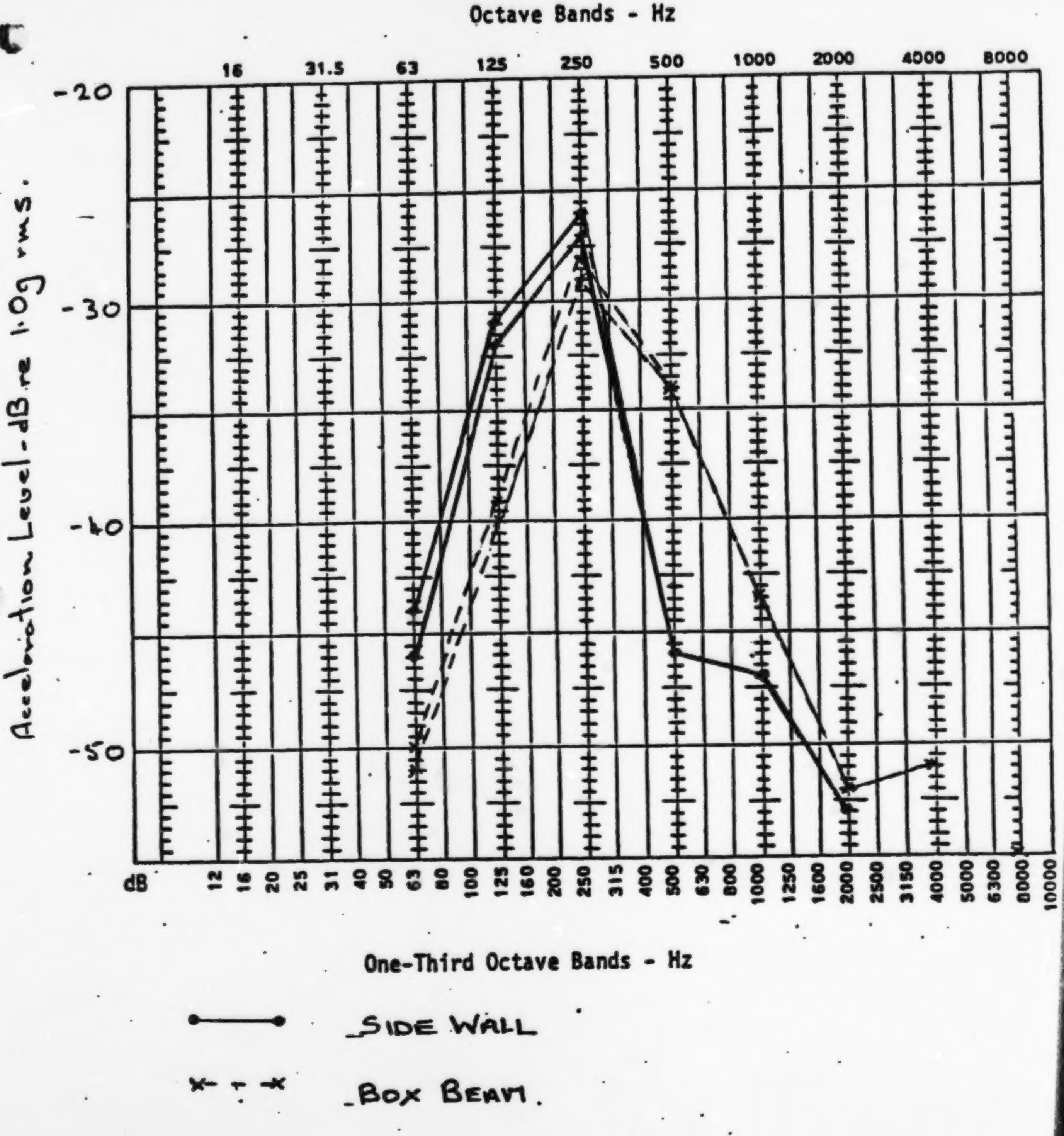


FIG. 9 — SIDE-WALL AND BOX BEAM VIBRATION — ACCELERATING

BEAM VIBRATION - ACCELERATING

APPENDIX 3

RESPONSE TO QUESTIONS OF THE TECHNICAL ADVISORY COMMITTEE RE: HAMILTON-WENTWORTH RAPID TRANSIT PROJECT NOISE AND VIBRATION IMPACT ASSESSMENT

WILSON, IHRIG & ASSOCIATES, INC.
ACOUSTICAL CONSULTANTS

5776 BROADWAY
OAKLAND, CA
U.S.A. 94618
(415) 658-6719

November 6, 1981

Mr. Jack Collins
Urban Transportation Development
Corporation Ltd.
2 St. Clair Ave., W.
Toronto, Ontario M4V 1L7
Canada

Subject: Response to Questions of the Technical Advisory Committee re Hamilton-Wentworth Rapid Transit Project Noise and Vibration Impact Assessment

Dear Mr. Collins:

This letter presents our response to the questions that the Technical Advisory Committee raised after their review of the preliminary version of our report, "Hamilton-Wentworth Rapid Transit Project Noise and Vibration Impact Assessment". In addition, enclosed is a final version of the report, suitable for reproduction, which incorporates the changes and additions that we discussed via telephone on November 4, 1981. Copies of References 5 and 6 are also enclosed for inclusion as appendices.

The following is our response to the eight areas of concern voiced by the Technical Advisory Committee:

I. What will be the increase in wayside noise in areas near track switches? - At the present time it is not known where the track switches will be located, however it is known that there will not be any in the downtown area with single guideway (north of Beckley Street) and that there will be a total of seven or eight switch locations over the entire length of the system (not including the yard) generally located near a station. At BART, it has been observed that when the trains traverse a switch there is an increase in the maximum wayside noise level of approximately 6 dBA at a distance of 50 ft. This increase is due to the impact noise of the wheels traversing the rail gaps at the frog of the switch. It should be noted that the actual noise of the wheels traversing the gaps will be of a shorter duration than the entire passby.

We feel that the increase in noise due to ICTS trains passing through switches will have a negligible increase in the wayside noise impact from the system. This conclusion is based on the following: 1. The parapet wall which is an integral part of the guideway beam is proposed to be approximately 22 in. high except at the location of switches where the height of the parapet wall is proposed to be 36 in. high. This increase in height will help to reduce any increase in noise which would arise at the switches. 2. With the wayside noise increased by 6 dBA, operation at 15 to 20 mph would produce a maximum wayside noise level of 66 dBA at 50 ft which is still acceptable at even the most noise sensitive community area. 3. At some new rail transit systems, consideration has been given to the switch mechanism with a closing frog which eliminates the gap and thus eliminating most of the potential increase in noise. This could be a matter for investigation during final design.

II. Is there an increase in wayside noise in areas near curves? - With older transit systems, trains traveling on curves have produced higher levels of wayside noise than the same trains traveling on tangent track. This increase in noise is usually in the form of squeal due to the stick-slip mechanism between the wheel and rail on tight curves. The ICTS transit vehicle will have a radial or steerable truck which will completely eliminate wheel squeal on all but perhaps the tightest curves. At the tightest curves, the train speed will be 15 mph which will ensure that wheel squeal will be eliminated or just barely perceptible, but even if just barely perceptible, the increase in noise level at these locations will not be enough to significantly increase the wayside noise level.

III. Will there be a difference in ground-borne noise and vibration due to different soil profiles between Kingston and Hamilton? - The ground-borne noise and vibration that we have predicted for ICTS trains passing by is, as stated in the report, based on the vibration measurements made from aerial and at-grade operations of an ICTS vehicle at the Kingston test facility. In addition, these predictions have utilized ground-borne noise and vibration data from other rail transit systems operating in subway, primarily the Toronto Transit System, since there is no subway test section at the Kingston test facility. The soil conditions in Toronto are probably similar to Hamilton.

For this study we have extrapolated from these baseline data and utilizing a computerized prediction program have predicted the ground-borne noise and vibration in representative buildings on Table IX. At this time detailed soil borings have not been made to determine the exact type of soil along the different sections of the alignment. However we have assumed that the tunnel will be founded in rock and that the vibration will be primarily transmitted through rock. This is a worst case assumption, since ground vibration is attenuated at a greater rate in soil than in rock. These ground-borne noise and vibration predictions can be refined during final design once the exact tunnel plan and profile have been determined and when soil boring data becomes available to determine correspondence or correlation with other areas such as Toronto.

Regarding ground-borne noise and vibration from aerial structure operations, these levels will be extremely low and will be dominated by the airborne noise produced by the trains. Only when the aerial structure column footings are in contact with a building foundation, or within a few meters of a building foundation will there be potential for vibration intrusion from train operations on aerial structure. At this time it is not possible to indicate where these locations will be since the locations of the aerial structure support columns have not been determined. However, as stated in the report, during final design, when the location of the support columns and depth of the column footings are known, then the potential vibration impact can be minimized by proper location of the columns and by vibration isolating the column footings from the building foundation at those locations where the support columns must be located within several meters of a building. Where there are any potential problems, special bearing pads between the girders and columns can be used to decrease the vibration to acceptable levels.

IV. Will there be community areas with a possible increase in noise levels? - As discussed in the report, the introduction of the ICTS to Hamilton will not increase community noise levels. However in the areas of the two stations in the Mountain area, bus routing will be changed extensively, with an increase in the number of buses in these areas. There is the potential for a small increase in the community noise level during peak traffic hours along some of the major streets near these stations, which is discussed in more detail in the report.

V. Isn't the unsprung mass the important factor in ground vibration, not the vehicle mass? - Yes, this statement is basically correct. The indication of the crush load mass of the vehicle has nothing to do with the noise and vibration produced. The crush loading is indicated only to give the reader a relative idea of the differences in system characteristics between typical heavy rail systems and the proposed ICTS.

VI. What is the noise level anticipated for a 4-car train? - Our anticipated noise level from a 4-car train is approximately 2 dBA more than that from a 2-car train. Usually, doubling the source (ie. 2-car train to 4-car train) would result in a 3 dBA increase. However, this is for point sources. For the case of transit train passbys, the noise level is increased by only a small amount, while the passby time is somewhat greater, since now the train length is twice as long.

VII. What will be the noise impact of two trains passing each other at the same time? - Obviously in the double guideway areas, ICTS trains will be passing each other. The resulting increase in noise level will be minimal and of very short duration since the time duration that it takes the two trains to pass each other is half the time of a normal train passby. The resulting noise levels can be determined by using the data presented on Table VIII. For a person standing on the ground, the increase in noise level during the time the two trains are passing is about 1 dBA which would not be noticeable. At guideway height the increase in noise level during the time the two trains are passing is about 2 dBA, which as for the case of a person standing on the ground would not be noticeable, since it usually takes at least a 3 dBA difference in noise level to be just noticeable to the average person.

VIII. What about the increase in noise at the tunnel portals? - There will be no increase in noise at either tunnel portal for trains traveling either in or out of the tunnel. The noise will be the same as that indicated on Table VIII.

It is hoped that the answers presented here satisfy the concerns of the Technical Advisory Committee. Please let us know if you have any additional questions or comments.

Very truly yours,

WILSON, IHRIG & ASSOCIATES, INC.

Steven L. Wolfe

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Project Manager

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